INLAND WATERS BRANCH

# *Hydrogeology and Groundwater Resources of the Gravelbourg Aquifer, Saskatchewan*

*R. ALLAN FREEZE*

SCIENTIFIC SERIES NO. 6

DEPARTMENT OF ENERGY, MINES AND RESOURCES

# HYDROGEOLOGY AND GROUNDWATER RESOURCES OF THE GRAVELBOURG AQUIFER, SASKATCHEWAN

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Cat. No.: M26-502/6

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# Acknowledgments

This report was originally submitted as a Master's thesis to the University of California at Berkeley while the author was on educational leave from the Geological Survey of Canada.

Professor P. A. Witherspoon of the University of California gave advice and assistance in the field program and critically read the report. Professors D. K. Todd and R. E. Goodman also provided valuable comment. The friendly co-operation shown by the Town of Gravelbourg, the Rural Municipality of Gravelbourg, and the local farmers was a significant contribution to the success of this investigation. S. Whitaker's explanations on the Pleistocene geology of the area were much appreciated. Excellent assistance in the field was provided by M. L. Parsons and D. W. Allman.

Thanks are also due to Dr. H. E. Robertson, Director of the Saskatchewan Department of Health Provincial Laboratory in Regina where several chemical analyses were carried out, and to Dr. R. M. Brown of the Environmental Research Branch of Atomic Energy of Canada Ltd., Chalk River, Ontario, who supervised the tritium analyses.

Abstract

The groundwater flow pattern in the Gravelbourg aquifer has been delineated by a number of hydrogeological mapping techniques. Quantitative characteristics of the aquifer were determined from one pumping test.

The aquifer underlies an area of about 85 square miles of the Gravelbourg plain in Southern Saskatchewan. It consists of stratified sand laid down during the retreat of one of the Wisconsin ice advances, together with associated thin outwash or fluvial sands and gravels. The aquifer is overlain by a succession of less-permeable Pleistocene sediments, and is underlain by the poorly permeable shale of the Cretaceous Bearpaw Formation. The bedrock surface in the Gravelbourg area shows a broad valley opening to the northeast, which controls the extent of the stratified drift.

Flow through the aquifer is essentially horizontal, with some discharge occurring through the overlying sediments at the downstream end of the aquifer. The major discharge, however, is into Old Wives Lake.

Recharge occurs through the glacial till and the silty clay phase of the stratified drift from the adjacent morainal upland areas and from the upstream part of the overlying plain. The water from the aquifer is sodium sulfate water, high in total dissolved solids (2500 to 5500 ppm), barely potable without treatment, and unsuitable for irrigation.

The maximum transmissibility of the aquifer is 5200 Imperial gallons per day per foot and the coefficient of storage is $0.92 \times 10^{-3}$. The horizontal permeability is 104 Imperial gal/day/ft$^2$. The vertical permeability of the glacial till is in the order of 3 - 20 gal/day/ft$^2$, as determined by tritium dating and pump testing evidence. The safe yield of the aquifer is 280 acre-feet per year; present utilization is 56 acre-feet per year.

# *Introduction*

## LOCATION

The town of Gravelbourg (population 2,500) is situated on the southeast corner of sec. 1, tp. 11, rge. 5, W. 3rd mer. (SE-1-11-5-W3) at latitude 49°52′ N. and longitude 106°33′ W. It is 50 miles south and 25 miles west of Moose Jaw, via highways 2 and 36.

The aquifer underlies an area of about 85 square miles northwest of the town. Including the adjacent recharge and discharge areas, however, the area studied covers about 324 square miles consisting mainly of tps. 10, 11, and 12 within rges. 4, 5, and 6. These nine townships form Rural Municipality No. 104, of which Gravelbourg is the seat.

Topographic map coverage south of latitude 50°00′N. is provided at a scale of 1:250,000 by map 72G of the National Topographic Series and at 1:50,000 by maps 72G/15- West Half, 72G/15- East Half, and 72G/16- West Half. These maps are published by the Department of Energy, Mines and Resources, Ottawa. For the area north of 50°00′ latitude the author used MTS Sectional Map No. 68, scale 1 inch to 3 miles. This map is now out of print. The location of the Gravelbourg area is shown on Figure 1.

## PRESENT STUDY

The initial investigation of the Gravelbourg aquifer formed part of a study of the Old Wives Lake drainage basin. The aquifer plays an important role in the hydrogeology of the basin, in that it constitutes one of the few major occurrences of a well-defined geological deposit of relatively high permeability acting as a groundwater conduit. Further, as it is extensively tapped by water wells, data are readily accessible for study. The many flowing artesian wells in the area are also of interest.

A groundwater study of this type has two main objectives:

(1) An explanation of the groundwater flow patterns. The nature of the Gravelbourg aquifer invites such a study and it is hoped that this report will constitute a type case of a regional groundwater flow system.

(2) An evaluation of the economic importance of the aquifer. This is especially important on the semi-arid Canadian prairies where it is imperative that all available water resources be carefully delineated.

In this report, the two objectives are kept separate, with the more academic problem of groundwater flow patterns treated under the heading *Hydrogeology* and the practical aspect discussed under *Groundwater Resources.*

The field work was done in the summer of 1963 and consisted of an inventory of existing wells, the collection of water samples and an interpretation of their chemical analysis, a drilling program, the installation of a nest of piezometers, and a pump test conducted on an existing well field. Geological control was obtained by field observation, from the interpretation of the drilling program, and by reference to existing publications, provincial well records, and seismic shot-hole data.

The aquifer referred to is a sand and gravel formation of proglacial origin and Pleistocene age. It is of limited areal extent, and occurs between 85 and 175 feet below the surface. It is *not* to be confused with the Gravelbourg Formation, a 50 to 250-foot thick sequence of shale, sandstone, and carbonates of Jurassic age, which underlies the whole of southern Saskatchewan at depths of 3,000 to 5,000 feet.

## PREVIOUS WORK

The bedrock geology of southern Saskatchewan was first mapped by Fraser, *et al.* (1935) at a scale of 1 inch to 8 miles. A later geological map of the whole province at 1 inch to 20 miles was published in 1947 (Geol. Surv. Can., Map 895A). Johnston, W.A., Wickenden, R.T.D., and Weir, J.D (1948) published a map of the surficial deposits of southern Saskatchewan at a scale of 1 inch to 6 miles, and Mitchell, J., Moss, H.C , and Clayton, J.S. (1947) published a soil map of southern Saskatchewan at a scale of 1 inch to 6 miles. Both maps were very useful in the present study. The soil map has the advantage of having been prepared with very close control.

Following the years of drought on the Canadian prairies

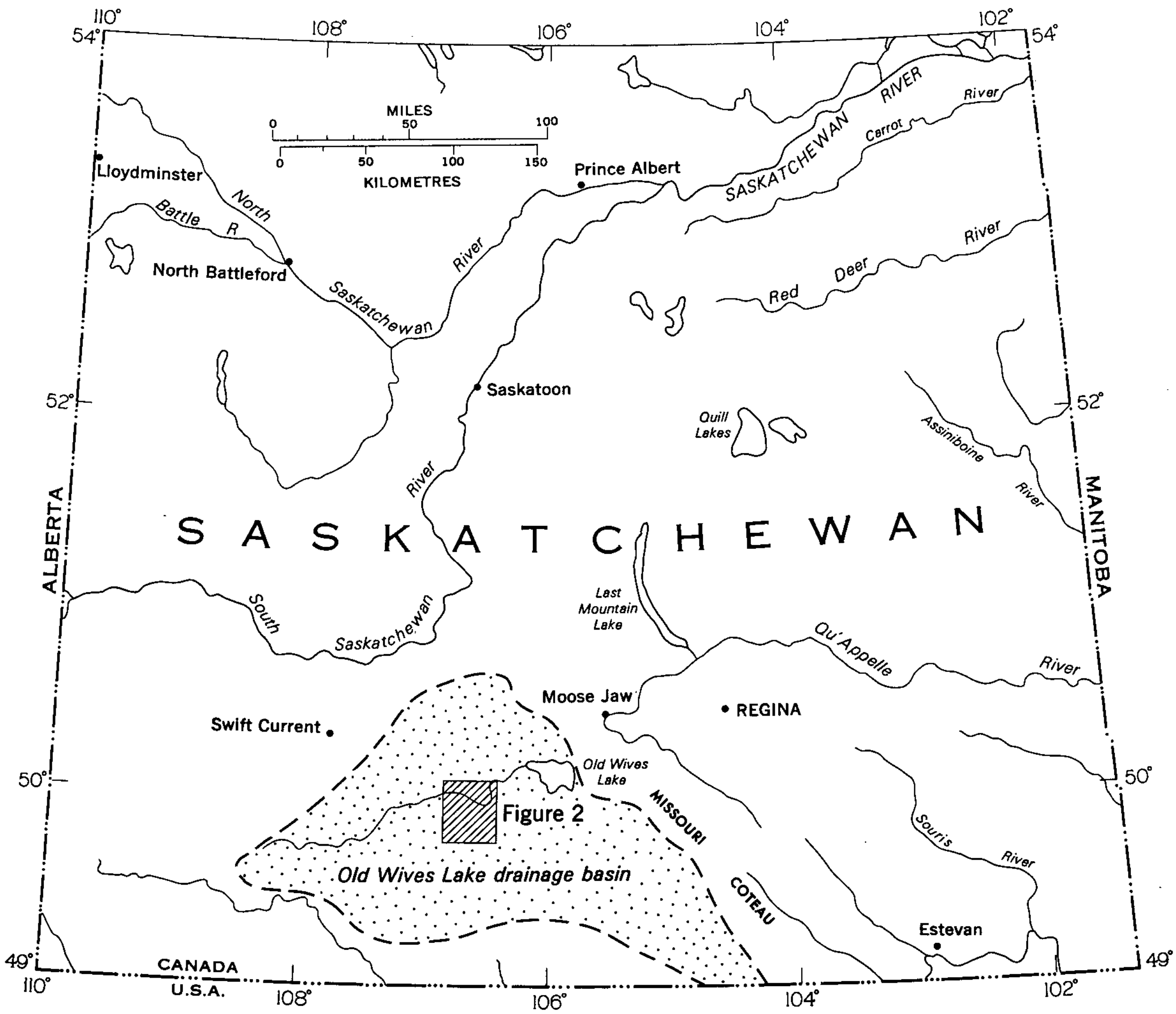



*Figure 1. Index map showing location of Gravelbourg area.*

in the early 1930's, the Geological Survey of Canada carried out a study of the groundwater resources and presented their results in a series of Water Supply Papers. Water Supply Paper No. 115 by MacKay, Beach, and Cameron (1936a) describes the Rural Municipality of Gravelbourg, and contains a wealth of basic information in the form of well records, chemical analyses, and descriptions of groundwater conditions on a very local scale.

In recent years many oil companies have run seismic profiles over the area and their shot-hole logs are on file with the Provincial Department of Mineral Resources in Regina.

The Saskatchewan Research Council is conducting a study of the geology of map-area 72G at a scale of 1:250,000.

# Physiography

## TOPOGRAPHIC FEATURES

The Gravelbourg area lies to the southwest of the Missouri Coteau and is therefore within the physiographic region defined by Acton, *et al.* (1960) as the Alberta High Plains. The Missouri Coteau is often referred to as the "second prairie step."

The physiographic trend in southern Saskatchewan is to the northwest. The area studied consists of three definite topographic zones, (Fig. 2, in pocket) which are a part of these northwesterly trending regional features. To the southwest a gently to moderately rolling upland ranges in elevation from 2,350 to 2,550 feet above sea-level; along the northern edge of the area is a similar upland but at a lower elevation. Local relief of 50 feet is common in these areas. Between the two uplands lies the Gravelbourg plain, a flat to gently undulating surface showing a local relief that seldom exceeds 10 feet. The maximum relief over the entire area is 350 feet.

## DRAINAGE

The Old Wives Lake drainage basin (formerly Johnston Lake) is an internal basin with the major drainage provided by Wood River and Notukeu Creek. These two streams rise in the southern uplands and flow northward towards Old Wives Lake, a large, shallow, saline lake.

Within the map-area, Wood River flows in a northerly direction across the Gravelbourg plain from Thomson Lake, an artificially-created reservoir, towards Old Wives Lake which lies about 8 miles to the northwest. It is joined by Notukeu Creek in sec. 27, tp. 11, rge. 4. Both rivers are meandering streams whose beds are incised into a much wider ancient flood plain. They are intermittent and are usually dry from September to March or longer. The maximum recorded discharge for Wood River (at station 5JA near Lafleche) is 10,620 cfs. Wiwa Creek, a smaller intermittent tributary, enters Wood River from the west in sec. 32, tp. 12, rge. 4.

Although these streams flow across the map-area, they do not actually drain it. A major feature of the glaciated Canadian prairies is the lack of an integrated drainage pattern, owing to the large areas of depressional storage created by the hummocky nature of the ground moraine. The result is a myriad of small internal drainage basins on the scale of potholes and sloughs. The part of the 'drainage area' that actually contributes surface runoff to the stream may therefore be very small. The large number of small sloughs in the Gravelbourg area and the lack of tributary streams leading into the rivers are shown on Figure 2. The drainage area is probably entirely confined to the flood plains. In the central clay plain, the underlying ground moraine produces a subdued undulating surface sufficient to halt effective runoff.

This lack of an integrated drainage pattern, together with the fluctuation of the boundaries of the contributing parts of the drainage area with annual and seasonal variations in rainfall and evaporation, makes hydrologic analysis of the Gravelbourg basin very difficult, as the 'drainage area' is regarded as the basic stable parameter in most hydrologic procedures.

## SOILS

The area is a part of the Brown Soil Zone and includes several soil associations (Mitchell, J., Moss, H. C., and Clayton, J. S., 1947). A soil association is defined as a local group of related soil profiles that belong to the same soil zone and occur on a similar type of parent material. The soil association together with the soil texture makes up the mapping unit in Saskatchewan.

Three soil associations occur in approximately equal abundance over the map-area (Fig. 3). The Haverhill Association consists of medium-textured soils (loam, clay loam) developed on glacial till; the Fox Valley Association is made up of medium-textured soils developed on silty glacial lake deposits; and the Sceptre Association features heavy clay soils on glacial lake clay. Two other associations, the Hatton and Chaplin, are present over very small areas only. The soil map (Fig. 3) has been used to interpret the surficial geology of the area (Fig. 6).

An important soil property, in terms of groundwater study, is the moisture storage capacity, which represents the moisture stored in a 4-foot depth of soil between permanent wilting point and field capacity. The following values (in inches of water) have been published by the Soil

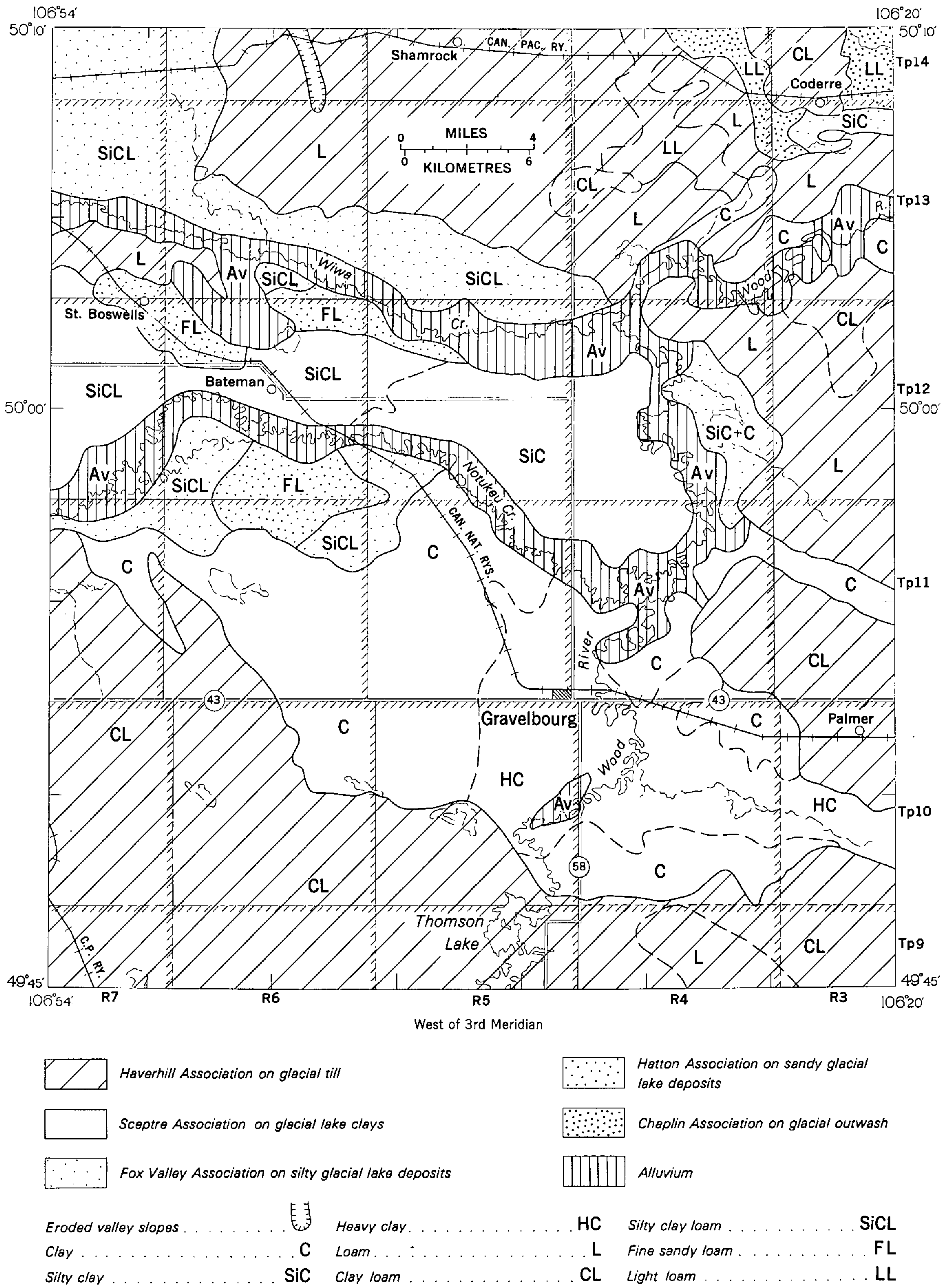



*Figure 3. Soil map of Gravelbourg area (after Mitchell, et al. 1947)*

**Table I Annual Precipitation and Potential Evapotranspiration at Gravelbourg, Saskatchewan, 1951-60 (inches)**

| | 1951 | 1952 | 1953 | 1954 | 1955 | 1956 | 1957 | 1958 | 1959 | 1960 | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Annual precipitation | 21.08 | 12.78 | 13.92 | 19.89 | 15.52 | 11.27 | 10.80 | 11.45 | 15.47 | 13.74 | 14.59 |
| Annual potential evapotranspiration | 20.54 | 22.59 | 22.05 | 22.10 | 22.50 | 22.29 | 22.49 | 23.28 | 21.59 | 22.91 | 22.23 |

**Table II Mean Monthly Precipitation and Potential Evapotranspiration at Gravelbourg, Saskatchewan, 1951-60 (inches)**

| | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean monthly precipitation | 0.65 | 0.78 | 0.78 | 1.23 | 1.50 | 2.95 | 1.90 | 1.97 | 1.12 | 0.49 | 0.60 | 0.62 | 14.59 |
| Mean monthly potential evapotranspiration | – | – | – | 0.96 | 3.26 | 4.35 | 5.41 | 4.35 | 2.77 | 1.13 | – | – | 22.23 |

Research Laboratory of the Federal Department of Agriculture at Swift Current (1956): loam, 6.2"; clay loam, 7.2"; heavy clay loam, 8.8".

## CLIMATE

The mean annual precipitation for the 10-year period 1951-60 is 14.59 inches and the mean annual potential evapotranspiration 22.23 inches (see Table I).

The writer has used the empirical method of Thornthwaite (1948) to evaluate the potential evapotranspiration in the area. Pelton, King, and Tanner (1960) made a study of mean temperature methods such as Thornthwaite's, and concluded: "Measurements of potential evapotranspiration indicate that mean temperature cannot be relied upon for general use in estimating evapotranspiration during short periods. Mean temperature methods can be used with limited success for long-period (growing season and annual) estimates of potential evapotranspiration, but energy balance methods are preferable if radiation data are available." Unfortunately, data available were insufficient to use a more sophisticated approach, such as the approximate energy budget of Penman (1948). A graphical description of the climate of an 'average year' is obtained if the mean monthly values of the precipitation and potential evapotranspiration (Table II) for the 10-year period are plotted together on a Thornthwaite diagram. In the 'average year' precipitation exceeds potential evapotranspiration from November to April, whereas in the summer months the situation is reversed (Fig. 4). From November to April, therefore, the soil moisture is being recharged (and a snowpack is being formed), but insufficient water is available to bring the soil (heavy clay) up to its moisture storage capacity of 8.8 inches. During the growing season the soil moisture is utilized until the storage has been depleted. A period of water deficiency then results. In Gravelbourg the 'average year' moisture deficit is 7.72 inches. There is no moisture surplus.

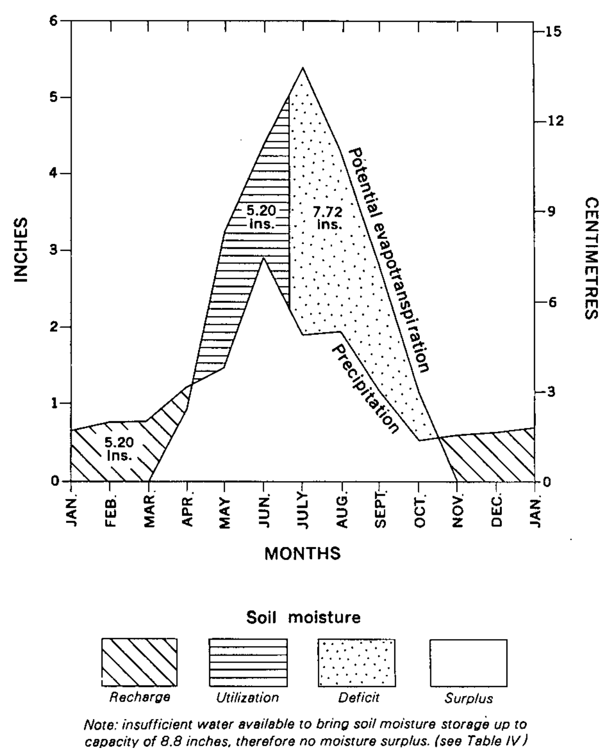



*Figure 4. Thornthwaite climate diagram, Gravelbourg, 'average year' for period 1951-60.*

**Table III Average Mean Monthly Temperature at Gravelbourg, Saskatchewan**

| | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average mean monthly temperature (°F) | 6.0 | 12.4 | 20.2 | 38.5 | 52.2 | 59.6 | 66.2 | 62.3 | 53.8 | 41.8 | 25.7 | 16.4 |

**Table IV Accounting Procedure, Gravelbourg, 'Average Year' for Period 1951-60**

| | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean Monthly Temperature | 6.0 | 12.4 | 20.2 | 38.5 | 52.2 | 59.6 | 66.2 | 62.3 | 53.8 | 41.8 | 25.7 | 16.4 | |
| Potential Evapotranspiration | – | – | – | 0.96 | 3.26 | 4.35 | 5.41 | 4.35 | 2.77 | 1.13 | – | – | 22.23 |
| Precipitation | 0.65 | 0.78 | ´0.78 | 1.23 | 1.50 | 2.95 | 1.90 | 1.97 | 1.12 | 0.49 | 0.60 | 0.62 | 14.59 |
| Difference | 0.65 | 0.78 | 0.78 | 0.27 | 1.76 | 1.40 | 3.51 | 2.38 | 1.65 | 0.64 | 0.60 | 0.62 | |
| Storage change | 0.65 | 0.78 | 0.78 | 0.27 | 0.83 | 0.66 | 0.91 | 0.62 | 0.43 | 0.17 | 0.60 | 0.62 | |
| Moisture storage | 3.37* | 4.15 | 4.93 | 5.20 | 4.37 | 3.71 | 2.80 | 2.18 | 1.75 | 1.58 | 2.18 | 2.80 | |
| Actual evapotranspiration | – | – | – | – | 2.33 | 3.61 | 2.81 | 2.59 | 1.55 | 0.66 | – | – | 13.55 |
| Moisture deficit | – | – | – | – | 0.93 | 0.74 | 2.60 | 1.76 | 1.22 | 0.47 | – | – | 7.72 |
| Moisture surplus | – | – | – | – | – | – | – | – | – | – | – | – | 0.00 |

Note: I = 28.23
* Average of January moisture storage for 10 years

Slightly different results will be obtained if the 10 years are treated separately and consecutively, using the *actual* monthly values of precipitation rather than the *mean* monthly values. When this is done, the mean annual moisture deficit is found to be 7.81 inches. A small moisture surplus occurs in one year out of ten.

The average mean monthly temperature at Gravelbourg for the period 1951-60 is shown on Table III. The mean annual temperature is 37.9°F.

A major inaccuracy of the method is its failure to take into account the fact that in northern latitudes frozen ground may hinder soil moisture recharge and much of the precipitation goes to build up a snowpack. When the snowpack melts in the spring, runoff is recorded even though the MS is supposedly zero.

The author has attempted to convey the impression that the Thornthwaite estimate of potential evapotranspiration used together with the accounting procedure outlined above cannot yield accurate quantitative results. It is felt, however, that in the absence of the data necessary for a more rational approach, the values are of the right order of magnitude and do have significance.

The accounting procedure (Holmes and Robertson, 1960) for the 'average year' using mean monthly values of precipitation and temperature from the 10-year period 1951-60 are shown in Table IV. The results are compared in Table V, with the results obtained by treating the 10 years separately and consecutively, and averaging the results over the 10 years. Since a moisture surplus (MS) will result in surface runoff and groundwater recharge, it is the most important single result of this procedure from a groundwater point of view. The 'average year' MS is zero whereas the 'mean annual' MS is 0.19 inch (see Table V). This is because only one of the 10 years had a MS (1.91 in.). When this is averaged over the 10 years, a 'mean annual' MS of 0.19 inch results. The one-year moisture surplus disappears statistically, however, when an 'average year' is considered. For this reason 'mean annual' figures are regarded as more correct in terms of the quantitative use of the values in water budget studies. These figures are referred to later in this report when the regional water balance is discussed as a method of arriving at an estimate of the available groundwater resources.

**Table V Comparison of 'Average Year' Values and 'Mean Annual' Values, Gravelbourg, 1951-60**

| | Average Year (inches) | Mean Annual (inches) |
|---|---|---|
| Potential evapotranspiration (PE) | 22.23 | 22.23 |
| Precipitation (P) | 14.59 | 14.59 |
| Actual evapotranspiration (AE) | 13.55 | 14.13 |
| Moisture deficit (MD) | 7.72 | 7.81 |
| Moisture surplus (MS) | 0.00 | 0.19 |
| Check calculation: MD = PE – AE | 8.68 | 8.10 |
| Check calculation: MS = P – AE | 1.04 | 0.46 |

# *Geology*

In southern Saskatchewan, glacial deposits of the Pleistocene continental glaciation overlie bedrock formations of Cretaceous and Tertiary age. In the Gravelbourg area, the Tertiary sediments have been removed by erosion and the bedrock underlying the glacial veneer is the Upper Cretaceous Bearpaw Formation.

The stratigraphy above the Jurassic System is shown in Table VI. Groundwater studies in the central prairies have generally been confined to this part of the geologic section because the Cretaceous Viking Formation and the Blairmore Formation are thought to represent the lowest aquifers from which water could be economically produced. Actually even these formations are out of economic reach at this time, owing to the high content of total dissolved solids in the waters of these aquifers (5000-7000 ppm) together with the high cost of demineralization.

A thick section of Jurassic and Palaeozoic sediments (about 6,000 feet) underlies the Cretaceous strata. Many of these formations contain oil and gas, and considerable study of the formation waters has been carried out by the petroleum industry. Although these waters do not represent economic sources of groundwater, they probably play an important role in the very large regional flow patterns.

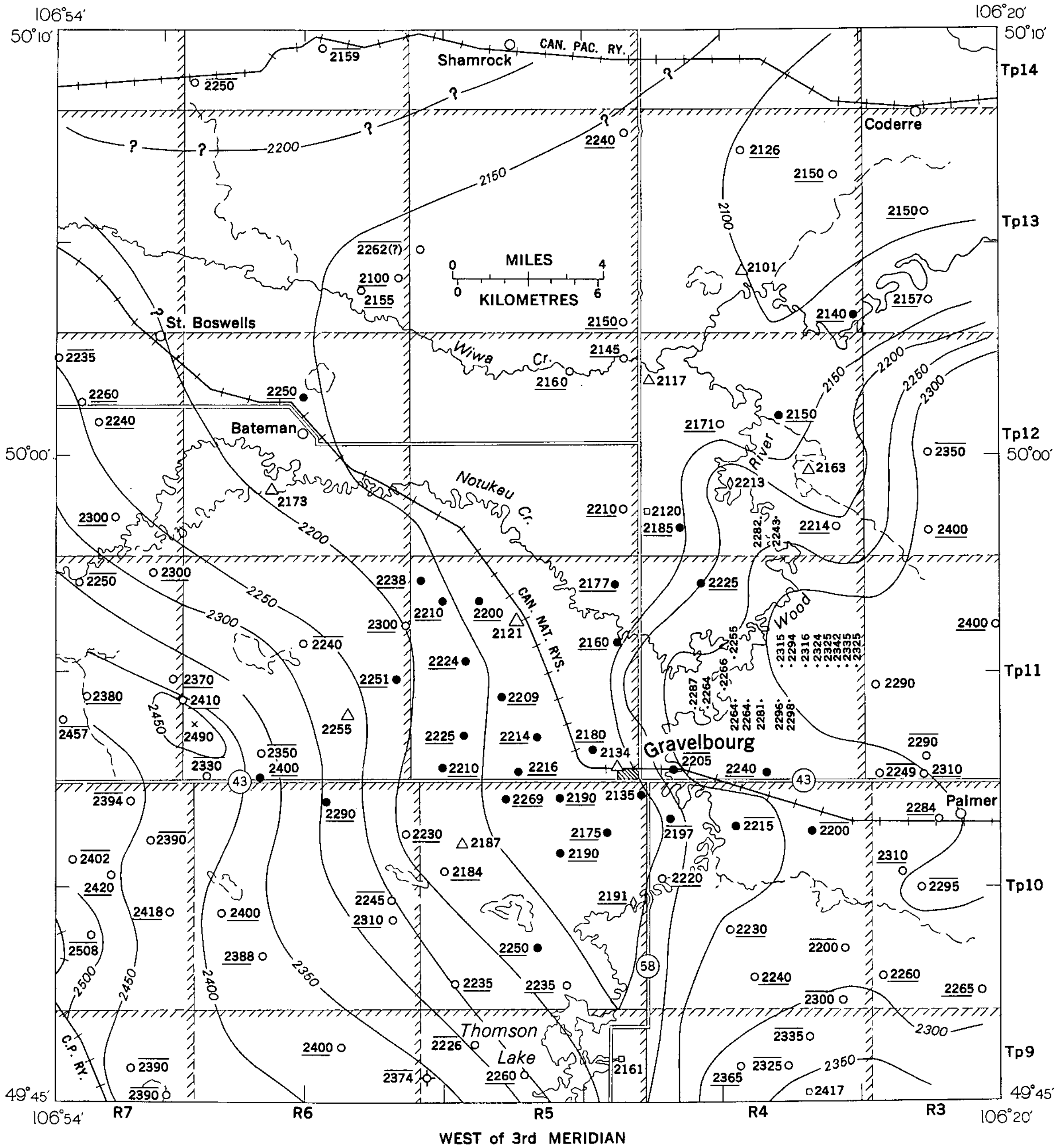
This report, however, is a study of a single Pleistocene aquifer, which is completely underlain by the relatively impermeable Bearpaw Formation. The discussion of the geology is therefore confined to a short description of the Bearpaw Formation (with emphasis on its preglacial topography) and a more complete discussion of the Pleistocene glacial geology. A knowledge of the geological details is prerequisite to an understanding of the aquifer occurrence.

## BEARPAW FORMATION AND BEDROCK TOPOGRAPHY

The Bearpaw Formation consists of dark grey, non-calcareous shale of marine origin (Fraser, *et al.*, 1935). In places the shale contains selenite crystals (ranging from tiny flakes to well developed, 4-inch crystals), and balls of radiating barite crystals (¼ inch to 2 inches in diameter). The X-ray diffraction pattern of an unfractionated sample

**Table VI Table of Formations**

| Era | Period | Epoch | Group or Formation | Lithology | Thickness (feet) |
|---|---|---|---|---|---|
| Cenozoic | | Pleistocene | | Glacial till<br>Glacial lake silt, clay, sand<br>Outwash sand and gravel | 0-200 |
| Erosional Unconformity | | | | | |
| Mesozoic | Cretaceous | Late Cretaceous | Bearpaw Fm. | Marine shale series, shale minor sandstone | 3,000-4,000 |
| | | | Belly River Fm. | | |
| | | | Lea Park Fm. | | |
| | | | Upper Colorado Gp. | Shale | |
| | | Early Cretaceous | Lower Colorado Gp. | | |
| | | | Viking Fm. | Sandstone, minor shale | 500 |
| | | | Blairmore | Sandstone, shale | |
| | Erosional Unconformity | | | | |
| | Jurassic | | | | |




Outcrop . . . . . . . . . . . . . . . . . . . . . . . . . . . ×

Drill-hole, 1963 . . . . . . . . . . . . . . . . . . . . . . . △

Dept. of Highways, bridge site exploration . . . . . . . . . . ◊

Well, inventoried, 1963 . . . . . . . . . . . . . . . . . . . ●

Well, GSC Water Supply Paper well records . . . . . . . . . ○

Seismic shot-hole . . . . . . . . . . . . . . . . . . . . . .2255 .

Oil well . . . . . . . . . . . . . . . . . . . . . . . . . . ⌖

Sask. Research Council, drill-holes 1964 . . . . . . . . . . ▫

Elevation of bedrock surface (in feet above sea-level) . . . . 2300

Bedrock surface above bottom of hole . . . . . . . . . . . . . . . . 2250

Bedrock surface below bottom of hole . . . . . . . . . . . . . . . . 2250

*Figure 5. Bedrock topography of the Gravelbourg area.*

of Bearpaw shale from the Gravelbourg area showed montmorillonite to be the chief of clay mineral, with illite the major accessory, and small amounts of kaolinite. The montmorillonitic (Christiansen, 1959, 1961), sometimes bentonitic (Petersen, 1954), nature of the Bearpaw shale has been reported by many other observers.

The only outcrop in the Gravelbourg area is at SW-7-11-6-W3, where several large ferruginous nodules are present and the shale is weathered to a light grey.

About 25 miles to the north in the Herbert-Morse area, the Bearpaw Formation contains extensive sand members, which are tapped for groundwater at depths of 300 to 700 feet. Electric logs of structure test-holes in the Gravelbourg area, however, show a section barren of sands down to a depth of 600 to 900 feet, at the Bearpaw-Belly River Contact. These strata dip 7 to 10 feet per mile to the northeast. The local detailed structure, if any, is not known (Fraser, *et al.,* 1935).

Permeability of the Bearpaw shale is very low and the water it does transmit probably follows minute fractures. Relative to the Gravelbourg sand and gravel aquifer the shale acts as a nearly impermeable boundary.

The primary data used in determining the nature of the Bearpaw surface underlying the glacial deposits (Fig. 5) are the elevation of outcrops and the position of the till-Bearpaw contact in drill-holes. Further data are supplied by well logs, seismic shot-hole logs, oil-well logs, and Provincial Department of Highways test-hole logs. Contours on Figure 5 represent the bedrock topography (i.e., the preglacial surface topography). They show that a broad, shallow, northward-trending valley existed prior to the advance of the Pleistocene ice sheet, and suggest that a tributary valley existed in the northern part of the area, with the whole system apparently discharging to the northeast. Recent Saskatchewan Research Council drilling has confirmed the presence of the valley to the south of the area (beneath Thomson Lake), as suggested by the contours. The nature of such preglacial bedrock valleys has been discussed by Christiansen (1962).

The bedrock surface is important for two reasons: first, in Pleistocene times it controlled to a large degree the nature and distribution of the glacial deposits; and second, owing to the low permeability of the Bearpaw shale, it now exerts a large influence on the groundwater flow pattern.

## PLEISTOCENE GEOLOGY

### Geomorphology

Figure 6 is a map of the glacial geology as adapted from the soil map (Fig. 3) of Mitchell, J., Moss, H.C., and Clayton, J.S. (1947). For example, the Haverhill Soil Association is, by definition, developed on a parent material of glacial till so that all areas in which the Haverhill Association occurs were considered to be underlain by glacial till. Similarly, areas of (1) lacustrine clay, silt, and sand, (2) outwash sand and gravel, and (3) alluvium were delineated from the other soil associations. The glacial landforms were then mapped on the basis of the extent of the various types of deposit, together with a study of topographic maps and airphotos, and field observations. Ground moraine and hummocky moraine were differentiated on the basis of the topographic soil phases, which are included on the original soil map (but not on Fig. 3). A more detailed study of the Pleistocene geology of NTS map-area 72G is now being carried out by the Saskatchewan Research Council. Their report will include that part of the Gravelbourg area south of latitude 50°00′.

#### *Glacial Landforms*

The topography of the ground moraine is gently undulating to gently rolling and shows local relief of 5 to 25 feet. This local relief is superimposed on the regional topography, which reflects the relief of the underlying bedrock surface. Hummocky moraine is moderately to strongly rolling and has a relief in the order of 20 to 40 feet. It is characterized by knob-and-kettle topography. Both types of moraine are composed almost entirely of glacial till, but include small lenses of sand and gravel. In some places, notably on the southern upland, the till is covered with a thin veneer (up to 3 feet) of lacustrine silt and clay. Many small, poorly developed melt-water channels trend in a southeasterly direction across the moraines.

End moraines have not been shown on Figure 6 as they cannot be delineated from the soil map alone. At least two such features are present in the area, however. One occurs along the southern edge of the hummocky moraine on the northern upland and is a relatively well developed ridge-like end moraine. The second, on the southern upland, is more difficult to distinguish, but the linear trend of hummocky moraine together with its correlation with the Aikins till sheet in the Swift Current area to the northwest (Christiansen, 1959) suggests that a marginal position of the Aikins ice advance must have occurred in this area.

#### *Proglacial Landforms*

The direction of ice retreat in southern Saskatchewan was to the northeast. As this was also the direction of regional slope, the retreating ice often formed closures with the surrounding topography, thus creating glacial lakes. To the northeast lake levels become successively lower. Consequently lacustrine deposits do not occur at a constant

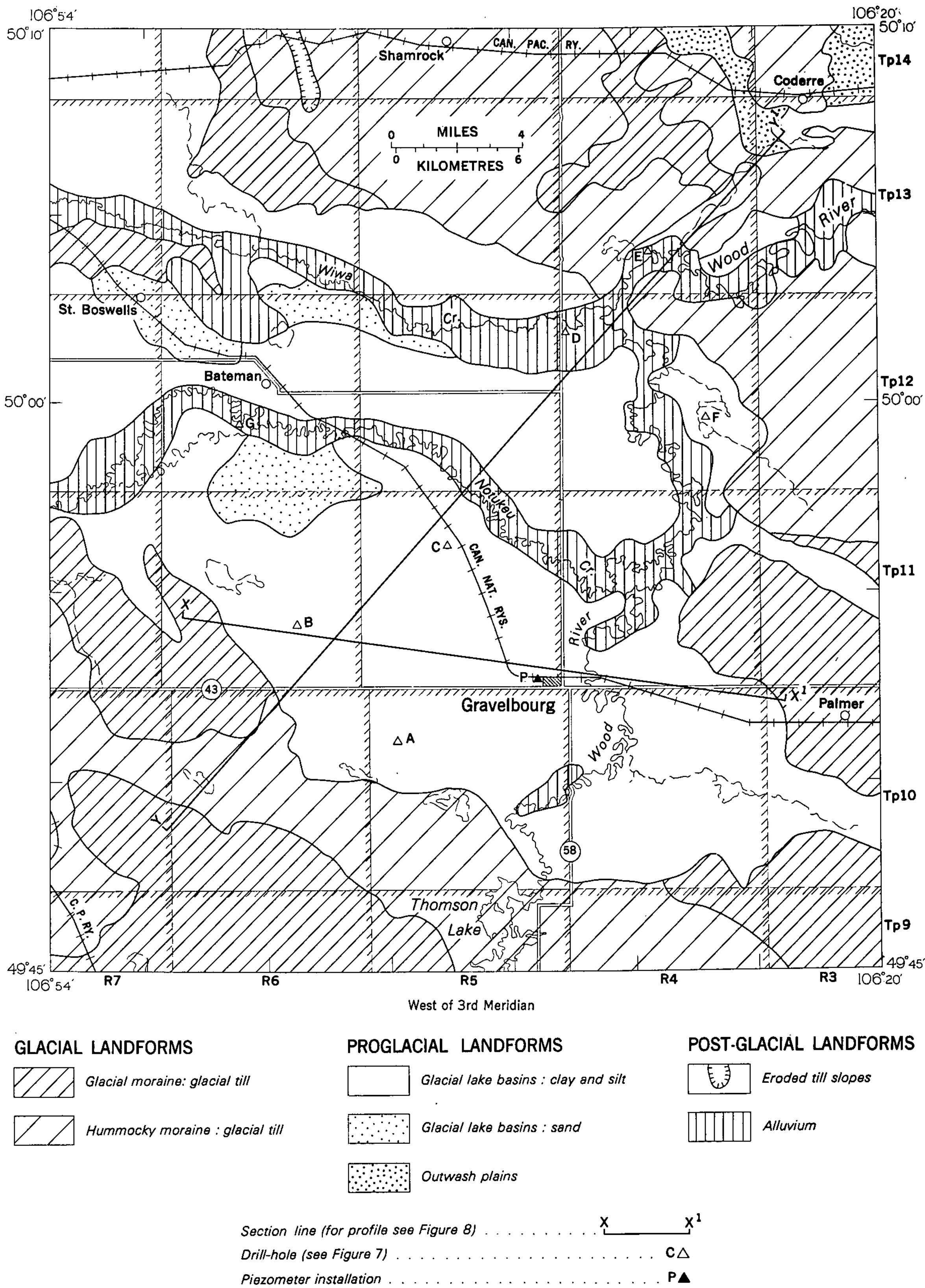



*Figure 6. Glacial geology of the Gravelbourg area.*

**Table VII Clay-Mineral Composition of the Aikins Till**

| Sample | Area | Location | Depth (feet) | Montmorillonite (%) | Illite (%) | Kaolinite (%) | Source |
|---|---|---|---|---|---|---|---|
| 1 | Gravelbourg | SE-35-9-5-W3 | 2 | 63 | 24 | 13 | GSC[1] |
| 2 | Gravelbourg | SE-35-9-5-W3 | 7 | 64 | 22 | 12 | GSC |
| 3 | Gravelbourg | SE-35-9-5-W3 | 10 | 57 | 29 | 14 | GSC |
| 4 | Swift Current | NW-16-19-13-W3 | 35-53 | 70 | 20 | 10 | SRC[2] |
| 5 | Swift Current | SE-24-15-14-W3 | 15-40 | 60 | 25 | 15 | SRC |

[1]Geological Survey of Canada
[2]Saskatchewan Research Council

elevation, nor are well-developed shorelines in evidence.

The Gravelbourg glacial lake basin is an example of this type of landform. It is a broad, flat plain, which becomes gently undulating where the lacustrine sediments are thin. The local relief is less than 10 feet. The sediments are composed of clay, silt, and sand, with clay and silty clay by far the most prominent. The sand shown on Figure 6 is fine sand (1/8-1/4 mm), with no coarser fractions present. Over most of the basin the lacustrine deposits are less than 30 feet thick.

Ice-marginal meltwater channels are generally associated with downhill retreating ice sheets and the formation of glacial lakes. These channels paralleled the ice front and carried the meltwaters into the glacial lakes. Many formed their own valleys during the glacial period, whereas others followed the course of existing bedrock valleys. Glacial lake Gravelbourg was the recipient of water and sediments from the northwest by way of the Neidpath channel, which was described by Christiansen (1959). To the southeast, beginning in tp. 11, rge. 3, an outlet channel from the former lake is in evidence. This channel follows the marginal position of the hummocky moraine and can be traced at least as far as Mazenod, 12 miles to the east. Another ice-marginal meltwater channel extends from the north into the map-area in tp. 14, rge. 6. In places it is partly filled with till, which suggests that the ice re-advanced across it after its formation. Small sand and gravel deposits are associated with it.

Two small outwash plains occur in the northeastern corner of the area. They exhibit a gently rolling topography of low relief and are composed of sand and gravel.

*Postglacial Landforms*

Wiwa Creek, Notukeu Creek, and Wood River all exhibit extremely wide flood plains with alluvial deposits 10 to 20 feet thick. It is possible that streams of the present size could have deposited this amount of alluvium, but it seems more likely that the present stream beds carried larger streams near the end of the glacial period. South of Gravelbourg, however, Wood River does not have a wide flood plain, and one must conclude that in this region it is still actively downcutting.

**Stratigraphy**

To delineate the stratigraphic succession of glacial deposits in the Gravelbourg area, the writer carried out a drilling program consisting of seven drill-holes and one piezometer installation. The location of the holes is shown in Figure 6 and the detailed geologic logs are contained in Appendix I. An interpretation of the geologic logs, showing several well-defined stratigraphic units, is given in Figure 7.

In all the holes except G,D, and E, a very soft, yellowish brown to tan, calcareous clay was encountered from the surface to the top of the glacial till. In holes D and E, which are on stream flood plains, interbedded clay, sand and gravel of alluvial origin directly overlie the till, showing that the streams have cut completely through the lacustrine clay. Hole G, on the other hand, showed a thick section of glacial lake clay underlying the alluvium and overlying a thin till layer. This hole is near the western inlets to the glacial lake and is thus nearer the sediment source.

The glacial till is a calcareous clay containing abundant silt (1/256-1/16 mm), sand (1/16-2 mm), and pebbles (2-64 mm). It is dark yellowish brown where oxidized, bluish grey where unoxidized. The pebbles are composed of quartz, feldspars, limestone, dolomite, and sandstone. Many selenite flakes and pieces of Bearpaw shale are present. The chief clay mineral is montmorillonite, with subordinate illite and kaolinite.

The clay-mineral composition of three till samples from the Aikins till-sheet of the Gravelbourg area and two from the Swift Current area are given in Table VII. Samples 1, 2, and 3 were taken from a section of till exposed on the shore of Thomson Lake at depths of 2, 7, and 10 feet. The relative abundances of the clay constituents given for samples 1, 2, and 3 are based on measurements of the

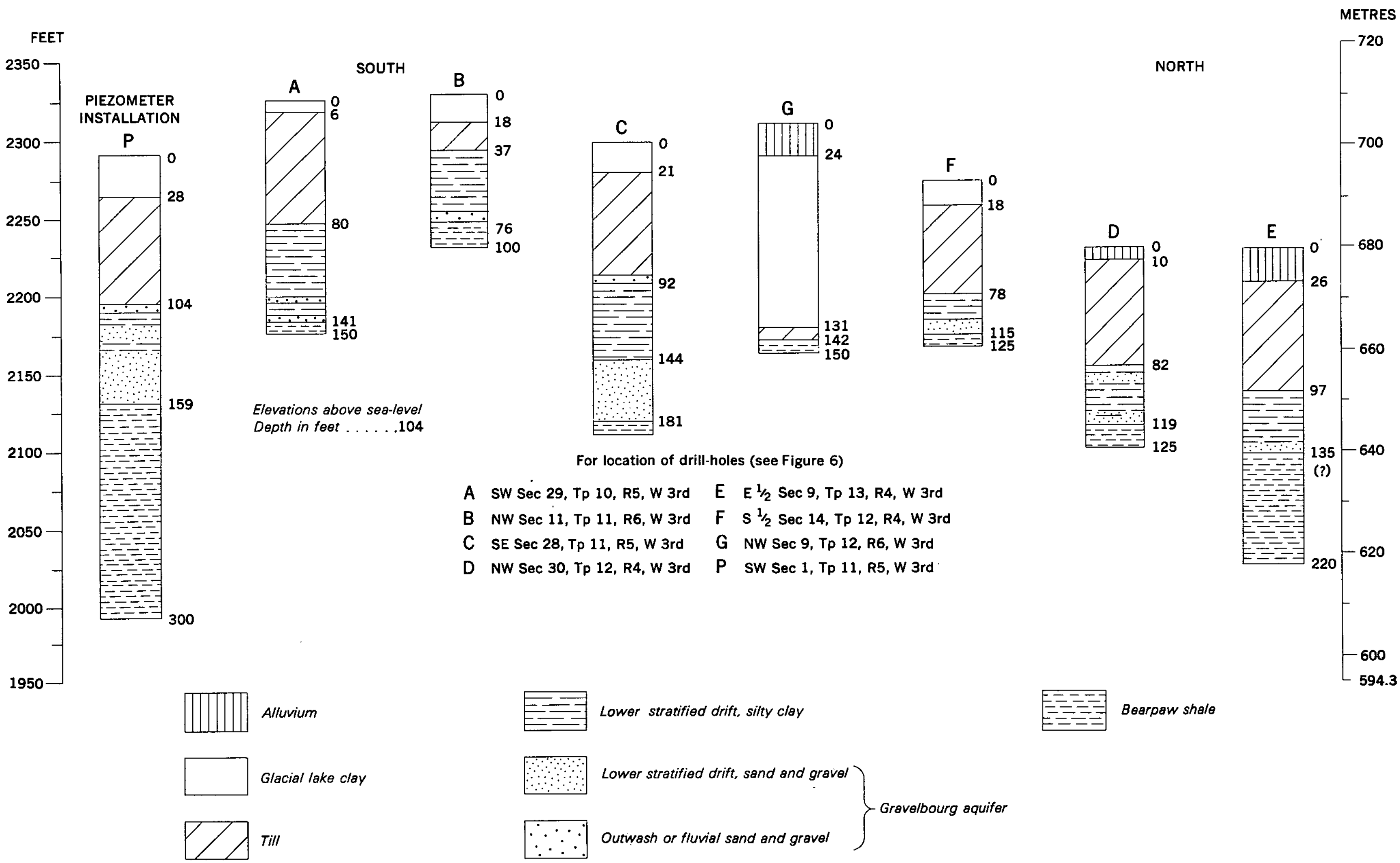



*Figure 7. Interpretation of geologic logs of drill-holes.*

**Table VIII Grain-Size Distribution of the Aikins Till**

| Sample | Area | Location | Depth (feet) | Sand (%) 2.0-0.05 mm | Silt (%) 0.05-0.002 mm | Clay (%) 0.002 mm | Source |
|---|---|---|---|---|---|---|---|
| 1 | Gravelbourg | SE-35-9-5-W3 | 2 | 27 | 36 | 37 | GSC |
| 2 | Gravelbourg | SE-35-9-5-W3 | 7 | 24 | 38 | 38 | GSC |
| 3 | Gravelbourg | SE-35-9-5-W3 | 10 | 26 | 37 | 37 | GSC |
| 4 | Swift Current | NW-16-19-13-W3 | 35-53 | 39.3 | 28.3 | 32.4 | SRC |
| 5 | Swift Current | SE-24-15-14-W3 | 15-40 | 41.4 | 26.4 | 32.3 | SRC |

Note: The sand, silt, and clay grade sizes in this table conform to the U.S. Dept. of Agriculture system, so that they may be compared with the published SRC data of Christiansen (1959). The Wentworth scale is used throughout the rest of the report.

intensities of the illite (001), montmorillonite (001), and chlorite (002) peaks from glycolated X-ray diffraction slides. Determinations 4 and 5, taken from Christiansen's (1959) analyses of the Aikins till, are included for comparison. The grain-size distribution for the three samples from the Thomson Lake section and the two comparative analyses from the Swift Current area are shown in Table VIII.

Between the base of the glacial till and the Bearpaw surface a considerable thickness of stratified drift was encountered in all holes except drill-hole G. This deposit has two phases: a silty clay, and a fine sand. The silty clay is a medium bluish grey, calcareous deposit with a somewhat granular appearance. In some samples black streaks of carbonaceous material were observed. X-ray diffraction showed the presence of montmorillonite, illite, and kaolinite in the clay. The sand is a fine (1/8-1/4 mm), dark grey, 'salt and pepper sand' composed of light-coloured subangular to subrounded equidimensional grains of quartz, feldspar, and calcite; and intermixed dark-coloured grains of feldspar, cloudy quartz, and subrounded basic igneous rock fragments. Quartz grains make up about 90 per cent of the sand. In some samples a very small percentage of mica was observed; in others, a small fraction of coarse sand to pebble gravel (1.0-64 mm) was present. The pebbles consisted of subrounded to subangular quartz, feldspars, carbonates, and dark rock fragments.

Associated with the stratified drift, generally at the basal contact with the Bearpaw, is another type of sand and gravel. This deposit, which is probably of outwash or fluvial origin, consists of fine to coarse sand (1/8-2.0 mm) and pebble gravel. The grains are angular to subrounded, and are composed of quartz, feldspar, carbonates, quartzite, red and yellow sandstone, red and brown shale, and dark rock

**Table IX Summary of Pleistocene Stratigraphy and Glacial History of the Swift Current Area (after Christiansen, 1959)**

| Period | Epoch | Age | Stratigraphic Unit | Moraines | Lakes | Channels |
|---|---|---|---|---|---|---|
| Quaternary | Pleistocene | Wisconsin | Upper stratified drift | | Lake Beechy | Thunder Crk. channel |
| | | | Leinan till | Clearwater Lake moraine | Lake Stewart valley | Neidpath channel #1 |
| | | | | | Lake Herbert | Neidpath channel #2 |
| | | | | Leinan moraine | | |
| | | | Unconformity | | | |
| | | | Loess; middle stratified drift; Aikins till | Aikins moraine | | Braddock channel |
| | | | Unconformity | | | |
| | | | Lower stratified drift; Wymark till | | | Pelletier channel |

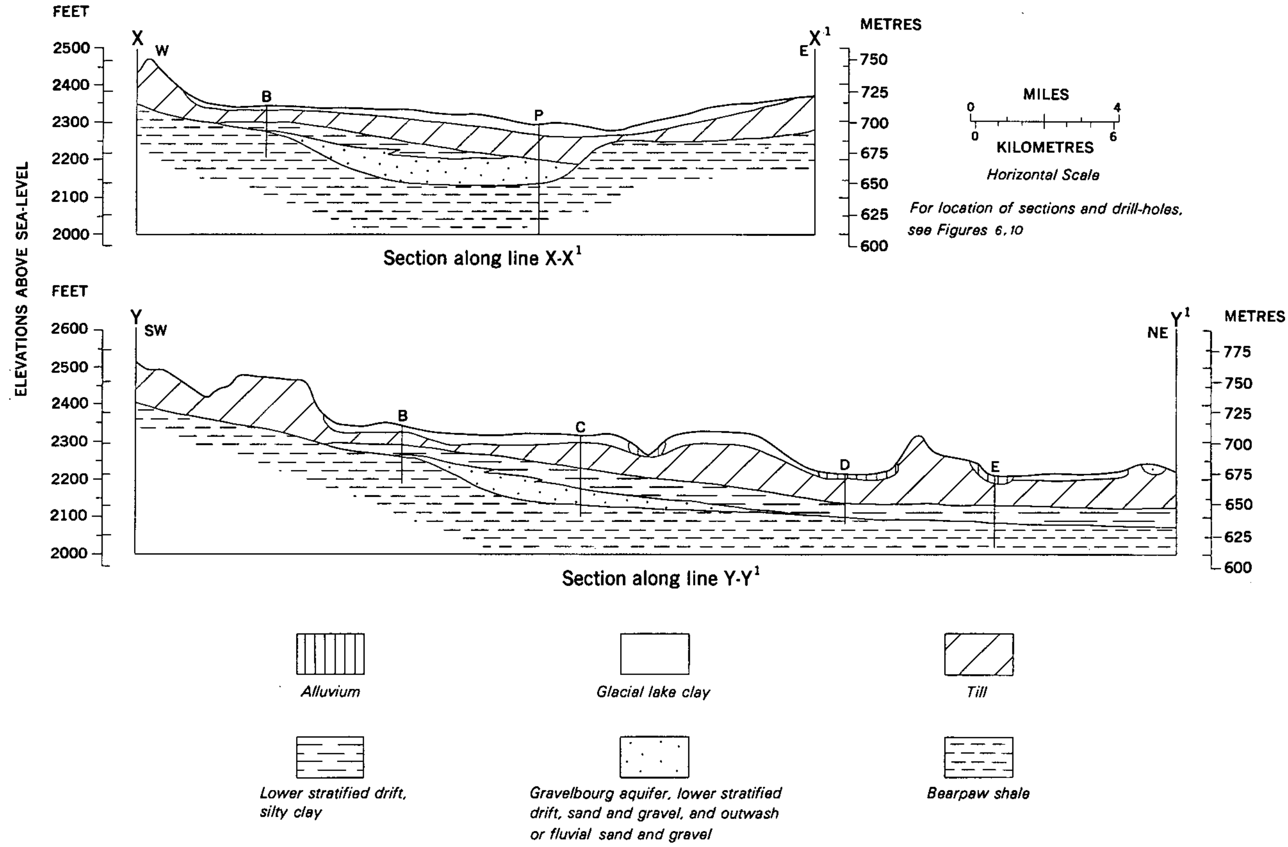



*Figure 8. Geologic cross-sections of the Gravelbourg area.*

fragments. The over-all colour is yellowish brown.

Two geologic cross-sections of the Gravelbourg basin, showing the extent of the various stratigraphic units are shown on Figure 8; the section lines are indicated on Figure 6. The sand phase of the stratified drift, where well developed (for example, at hole C), occurs at the base of the silty clay as shown on Figures 7 and 8. At the piezometer installation (P), the silty clay is practically absent and the entire thickness of the stratified drift consists of sand. In the other holes (A, B, D, E, F), the sand is either minor or absent.

This sand phase of the stratified drift, together with the associated outwash or fluvial gravels, constitutes the Gravelbourg aquifer. Its extent and thickness are more fully discussed under a separate heading.

### Glacial History

The glacial geology of the area immediately to the northwest has been mapped and described in detail by Christiansen (1959). In his report, which covers the Swift Current area (NTS-72J-West Half), he defined a stratigraphic sequence of three till-sheets and associated intertill deposits, and delineated the area over which they occur. He then developed the glacial history of the area, using the stratigraphy, the presence of ice-marginal channels, and the location of end moraines as the three main criteria. Table IX is a summary of the Pleistocene stratigraphy and glacial history of the Swift Current area. It is possible to correlate the deposits of the Gravelbourg area to a large degree with the succession outlined by Christiansen and thus to arrive at the glacial history. The relationship between the geology of the two areas is set out on Figure 9.

As stated earlier, the till exposed on the southern upland can be followed into the Swift Current area and correlated with the Aikins till. In the Swift Current area the southern margin of the Aikins till-sheet is marked by the Braddock ice-marginal channel (Fig. 9) and by the presence of the Aikins and moraine along part of its boundary. It is underlain by the older Wymark till, which extends farther to the south. In the Gravelbourg area, the margin of the Aikins till-sheet (i.e., the Aikins-Wymark contact) is difficult to determine. There is no channel, but a poorly developed end moraine position can be traced. (It should be noted at this point that the three tills, although possessing stratigraphic

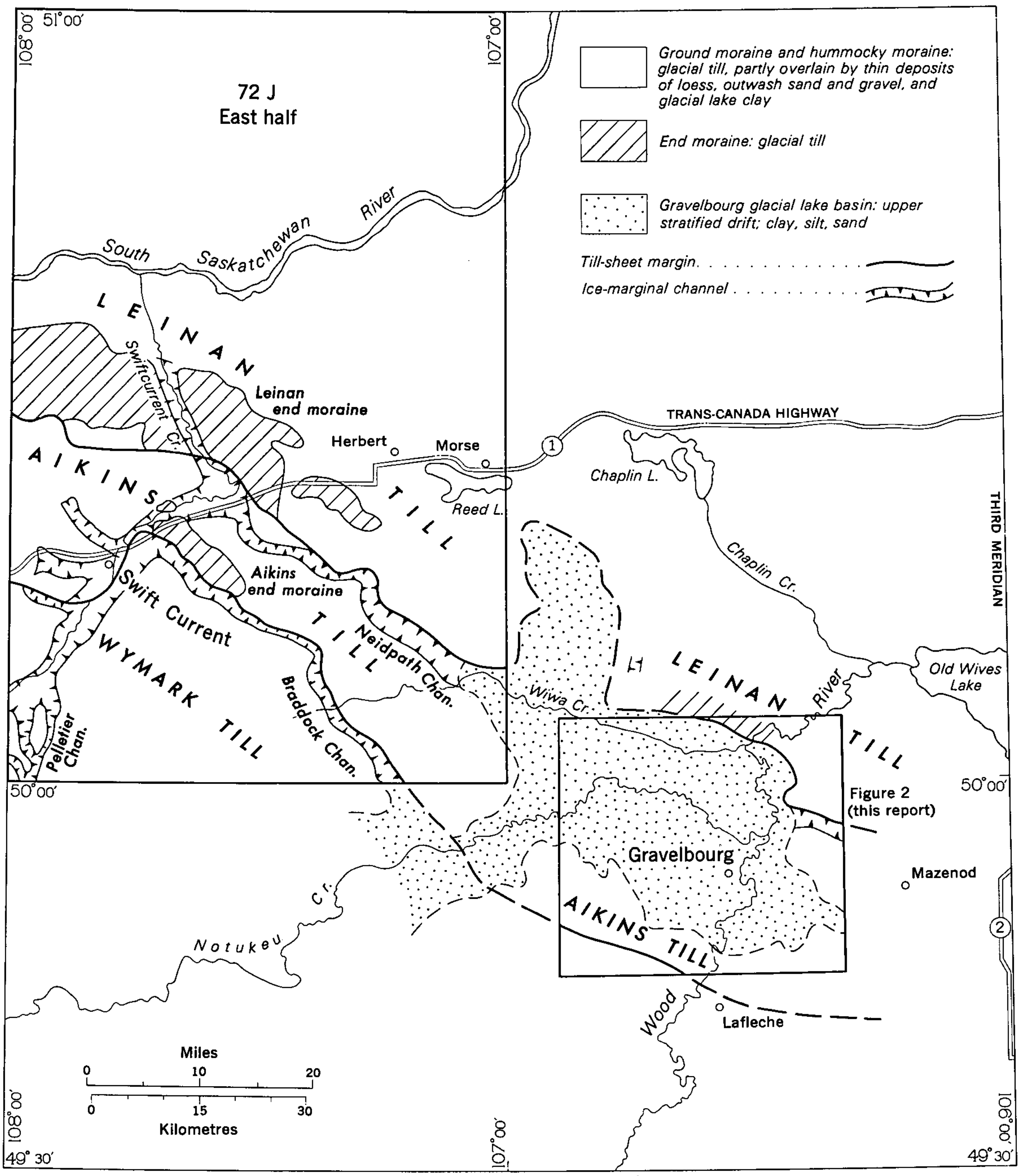



*Figure 9. Regional glacial geology of the Swift Current-Gravelbourg area (after Christiansen 1959, partly).*

significance, are not distinguishable on the basis of clay mineralogy, grain-size distribution, or plasticity properties.)

The stratified drift underlying the Aikins till in the Gravelbourg area is thus correlated with Christiansen's "lower stratified drift" and is therefore referred to by this name in this report. Christiansen stated (1959): "The lower stratified drift lies between the underlying Wymark Till and the overlying Aikins Till . . . (It) contains lacustrine marls, silts, and clays and fluvial gravels and sands. The lack of weathering upon the Wymark Till below the lower stratified drift suggests that the unit is a proglacial sediment which was deposited during the retreat of the glacier that deposited the Wymark Till." The till on the northern upland of the Gravelbourg area can be correlated with the Leinan till on the basis of the matching of marginal positions, and the Gravelbourg glacial lake clay is a proglacial sediment ("upper stratified drift") deposited during the retreat of the glacier that deposited the Leinan till. Neither loess nor "middle stratified drift" (Table IX) was encountered in the Gravelbourg area.

The glacial history of the Gravelbourg area involved the following phases.

1. Ice originally covered the entire area.

2. a) The ice retreated depositing the Wymark till.

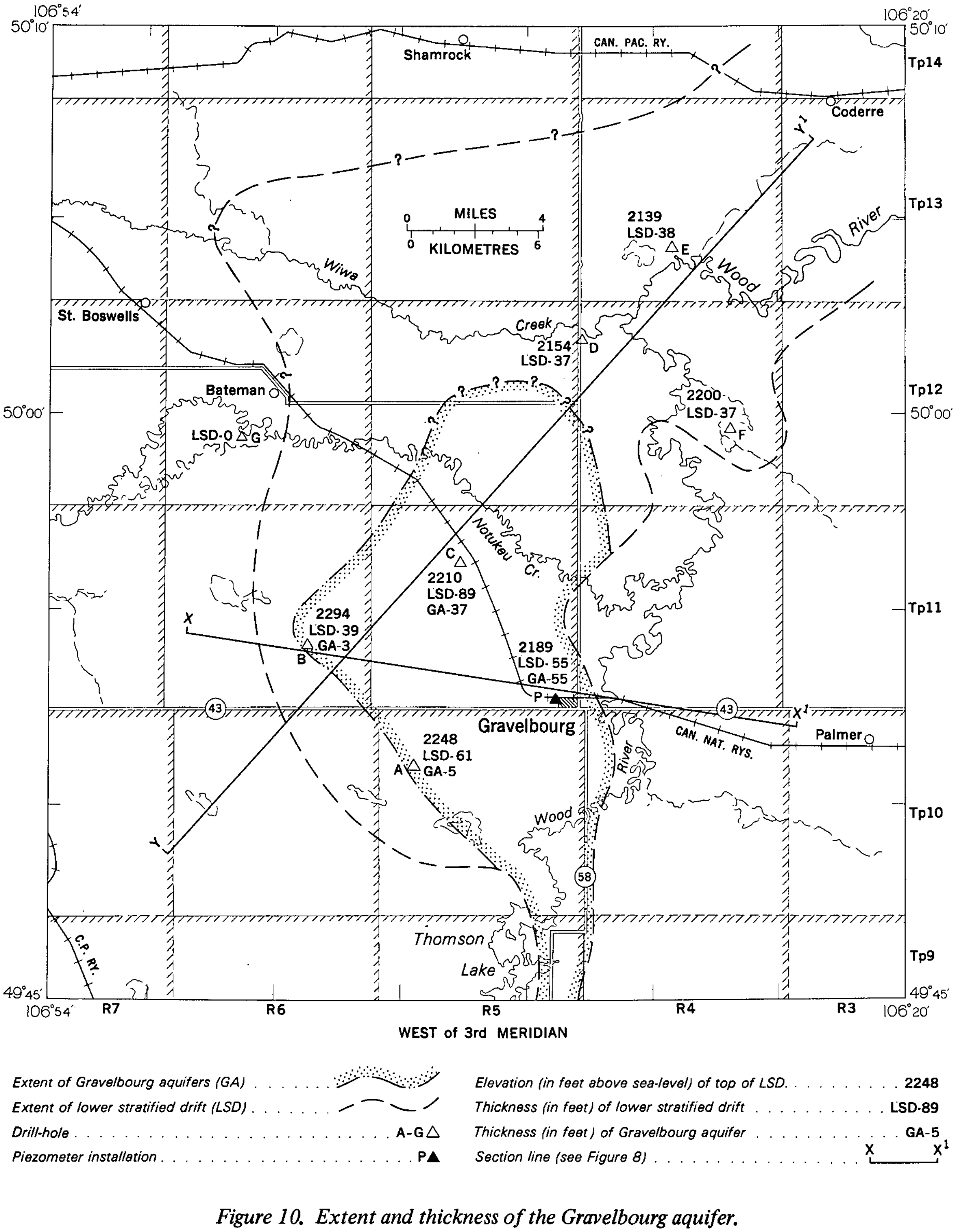



*Figure 10. Extent and thickness of the Gravelbourg aquifer.*

b) Proglacial "lower stratified drift" was deposited in a glacial lake ahead of the retreating ice front on top of the Wymark till. In the central basin of the Gravelbourg area, either no Wymark till was laid down or it has since been eroded, as the stratified drift rests directly on the Bearpaw.

3. The ice re-advanced to a position on the southern upland.
4. The ice retreated, depositing the Aikins till.
5. The ice re-advanced to a position at the southern edge of the northern upland.
6. a) The ice retreated, laying down the Leinan till.

   b) The Neidpath ice-marginal channel (Fig. 9) delivered sediments into glacial Lake Gravelbourg, thus depositing proglacial "upper stratified drift" (the present surficial glacial lake deposits).

The three till-sheets are all considered to be of Wisconsin age. The ice advanced to the southwest and retreated to the northeast.

**Extent and Thickness of the Gravelbourg Aquifer**

The foregoing interpretation of the stratigraphy and glacial history of the basin makes possible a fairly accurate estimate of the extent of the Gravelbourg aquifer. However, it is first necessary to consider the extent of the entire lower stratified drift unit lying between the till and the Bearpaw shale.

The elevation of the stratified drifts is plotted at each drill-hole (see Fig. 10). The surface of the stratified drifts is undulating with a high in the southwest gradually sloping towards the northeast. If this surface is then imagined to intersect the bedrock surface (Fig. 5) at the elevations indicated, the line of intersection represents the boundary of the lower stratified drift. Referring to Figures 5, 8, and 10, the lower stratified drift unit is seen to be a long lenticular deposit laid down in the broad preglacial valley. As mentioned in the previous section, it is of proglacial origin having been deposited in a glacial lake ahead of the retreating Wymark ice front.

The sand phase of the stratified drift attains its maximum thickness where the stratified drift abuts against the steep eastern wall of the bedrock valley near Gravelbourg. There, it comprises the entire stratigraphic unit. To the northwest and southwest the sand phases out into silty clay. Where both units are present, the sand underlies the silty clay. The outwash or fluvial sands and gravels that occur at the bedrock contact are also a part of the Gravelbourg aquifer, but they are not thick enough or continuous enough to constitute an aquifer independent of the sand phase of the stratified drift.

From available well records (MacKay, Beach, and Cameron 1936 a, b) and the above considerations, the postulated areal extent of the Gravelbourg aquifer has been outlined in Figure 10. Because of the scarcity of data, the northern limit of the sand must be considered as interpretive. The aquifer reaches its maximum thickness in tp. 11, rge. 5 near Gravelbourg, but there are insufficient data to draw an isopach map of the whole aquifer.

Recent drilling by the Saskatchewan Research Council has shown similar sands in the extension of the preglacial valley to the south of the map-area. It is assumed that these sands are a narrow extension of the aquifer as shown in Figure 10. The hydrogeologic study, however, was confined to the region north of latitude 49°45′.

# Hydrogeology

The basic tasks of the hydrogeologist are to determine:

1. The regional groundwater flow system;

2. Its relation to the surface hydrology through recharge and discharge; and

3. The quantitative hydrologic properties of any aquifers that may act as major flow paths in the system.

## THE ANALYSIS OF GROUNDWATER FLOW PATTERNS

Groundwater flow is governed by a potential field, which is expressed by the distribution of hydraulic head. Generally hydraulic head – usually known simply as head–is controlled by the elevation of the water table, which is in turn controlled by the topography, geology, and climate. Hubbert (1940) has shown the nature of the flow pattern resulting from a topographic high between two parallel effluent streams in uniformly permeable material (Fig. 11).

In an inhomogeneous formation, however, refraction of the flow lines occurs at the boundaries between media of different permeabilities. This refraction obeys the tangent law:

$$\frac{K_1}{K_2} = \frac{\tan \theta_1}{\tan \theta_2} \text{ (Fig. 12A).}$$

As an example, Figure 12B shows the refraction across layers of coarse and fine sand with a permeability ratio of 10. The limiting cases are those where $K_2 = \infty$ and $K_2 = 0$ (Fig. 12C). Where a medium of finite permeability borders on an infinitely permeable medium, the equipotential lines parallel the boundary and the flow lines terminate perpendicularly, whereas at an impermeable boundary the flow lines parallel the boundary and the equipotentials terminate perpendicularly on the boundary. Figures 12B.b and 12C.b should be kept in mind as apropos to the Gravelbourg conditions.

Thus, although topography is the main controlling factor, modifications are exerted on the flow system by the geological inhomogeneities. For this reason details of both the topography (Fig. 2) and the geology of the Gravelbourg area have been given in this report.

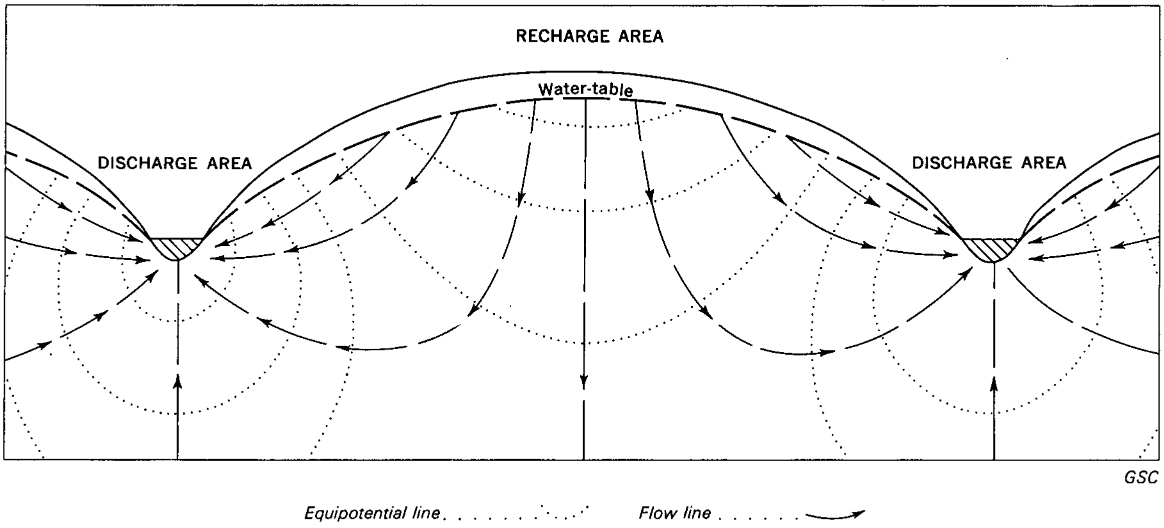
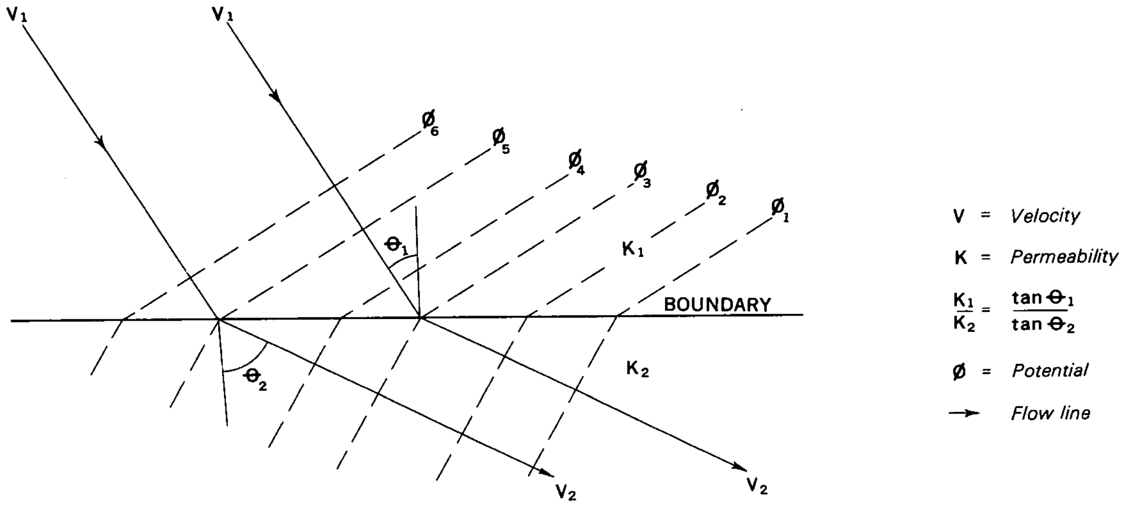
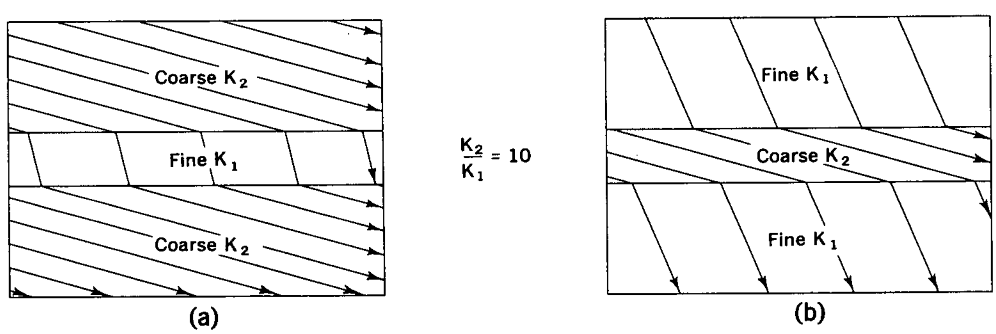


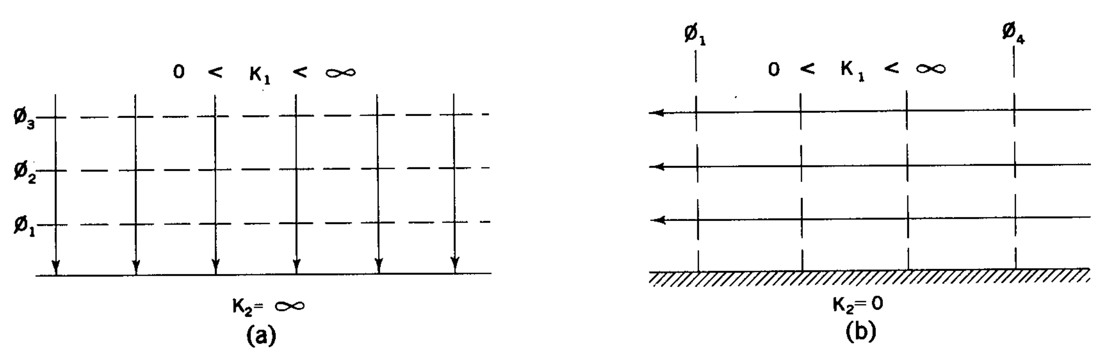

*Figure 11. Approximate flow pattern in uniformly permeable material between two parallel effluent streams (after Hubbert, 1940).*




A. Refraction of flow lines across a boundary between media of different permeabilities (after Todd, 1959)




B. Refraction of flow lines across layers of coarse and fine sand (after Hubbert, 1940)




C. Flow (a), from region of finite to one of infinite permeability; (b) along impermeable boundaries (after Hubbert, 1940)

*Figure 12. Refraction of flow lines in an inhomogeneous formation.*

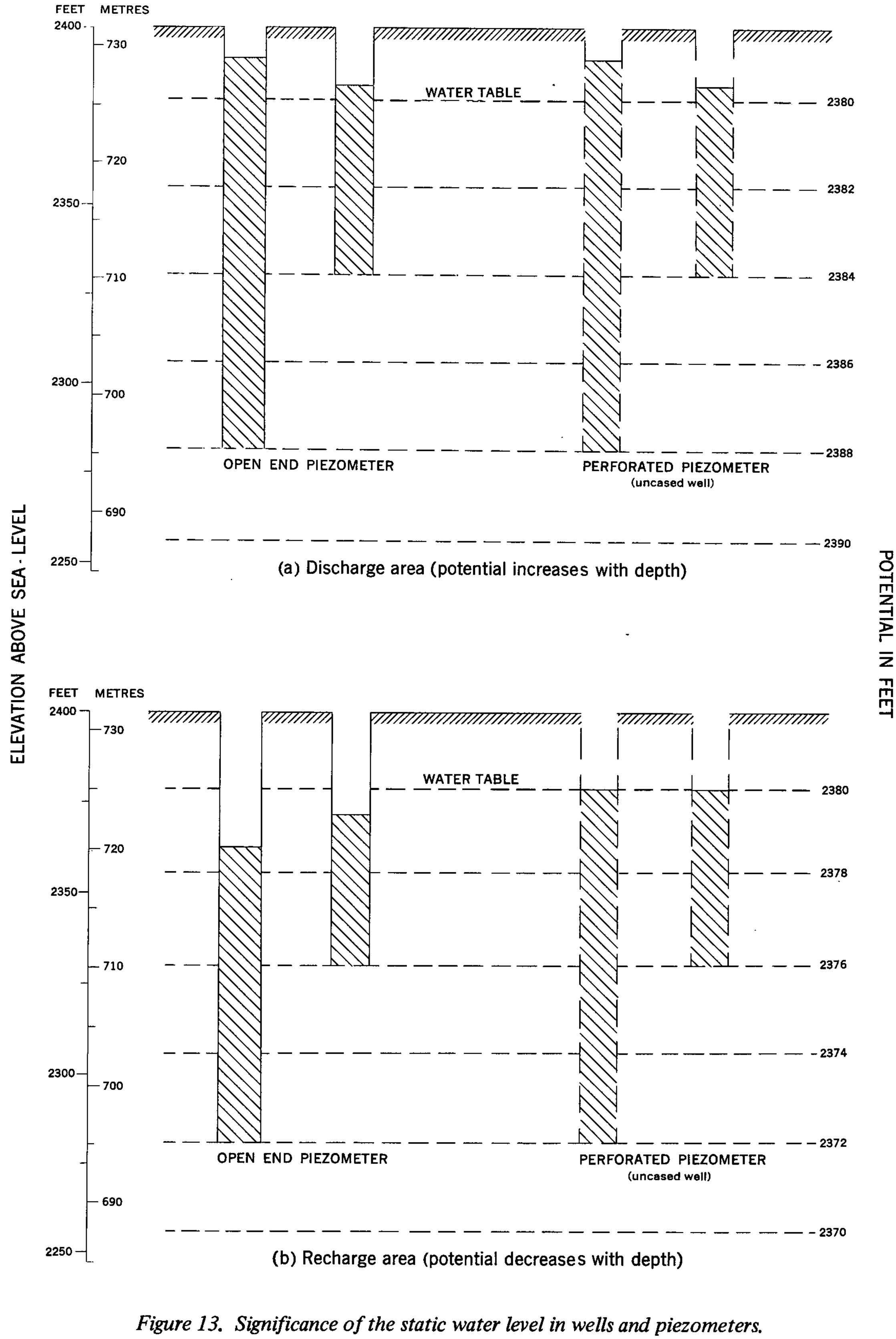



*Figure 13. Significance of the static water level in wells and piezometers.*

Using the topography and the geology as interpretive tools, it is possible to outline the actual existing flow pattern in the Gravelbourg area by the use of several types of analyses. These can be classified as follows:

1. Piezometric analyses
2. Hydrogeochemistry
3. Surface evidence of recharge and discharge areas
4. Theoretical approach.

## PIEZOMETRIC ANALYSES

Piezometric analyses involve the utilization, in various ways, of records of static water levels as measured in wells and piezometers. The static water level in a piezometer that is properly completed and open only at the bottom is a measure of the potential at the base of the piezometer. In discharge areas, the potential increases with depth so that the potential at the base is greater than the potential at overlying points. Therefore, in a homogeneous medium, even a well that is open all along its length (i.e., a perforated piezometer) will record a static water level representative of its base. In a recharge area, on the other hand, the potential decreases with depth, and the static water level in a well that accepts water throughout its saturated length will be at the water table. Figure 13 may help to clarify this point. In other words, the static water level in a well or perforated piezometer in a homogeneous medium is a measure of the highest potential encountered by the well.

In the more general case of a layered medium consisting of sediments of varying permeabilities, 'thieving' from one aquifer into another by way of the well is common. If the sediments in the low-potential layers (in either the recharge or discharge case) have a high permeability they will thus represent 'thief zones' and the water level recorded by the perforated piezometer will be slightly lower than in the ideal situations just described.

Measurements of static water levels may be used in several ways:

1. To construct flow nets in vertical sections across a basin;
2. To construct piezometric surfaces;
3. To distinguish between recharge and discharge areas by the use of plots of well depth versus depth to static water level.

### Piezometric Surface on the Gravelbourg Aquifer

In a homogeneous medium, the three-dimensional potential field can best be represented by equipotential contours on vertical and horizontal sections. These contours are actually the intersection of the equipotential surfaces of the potential field with arbitrary vertical or horizontal planes. The vertical section representation generally takes the form of flow nets, the horizontal section that of piezometric contour maps. Therefore only static water levels from wells that bottom at the elevation represented by the horizontal section should be used for the construction of a piezometric surface.

However, in a flat-lying aquifer with a permeability several orders of magnitude greater that that of the underlying and overlying formations, the assumption of flow parallel to its boundaries is valid (Fig. 12C-b); there will be no vertical component of flow and the equipotential surfaces will be perpendicular to the horizontal boundaries. Thus a piezometric surface drawn on the top of the aquifer is a valid representation of the potential along the length of the aquifer.

The relatively impermeable Bearpaw shale forms the basal boundary for the Gravelbourg aquifer and the aquifer has an artesian nature over most of its areal extent with the potential in the aquifer exceeding the potential in the overlying formations. Therefore a piezometric surface was constructed (Fig. 14) based on static water levels of wells penetrating the aquifer.

The assumption of horizontal flow in the aquifer is further justified by the results of the Gravelbourg piezometer installation described in the following section.

The piezometric head decreases from west to east across the aquifer with an average gradient of 5 ft/mile, and from south to north along the eastern edge. If flow lines in the direction of decreasing head are imagined to cut the equipotentials at right angles the nature of the horizontal flow within the aquifer is seen. The major recharge occurs along the southern and western boundaries of the aquifer, and the water leaves to the northeast. There is evidence of a piezometric low caused by pumpage around Gravelbourg.

Local residents tap a shallow sand at the base of the surficial glacial lake clay for water supplies rather than deeper wells into the Gravelbourg aquifer. For this reason, no measurements of potential on the aquifer are available in this area, and the configuration of the piezometric surface is uncertain.

Over a small area, near Gravelbourg the piezometric surface lies above the ground surface and flowing wells result. Over much of the rest of the area, the static water level in wells penetrating the aquifer is within 10 feet of the surface.

Only those water levels measured in the summer of 1963 were used in constructing the piezometric surface. Earlier measurements included in Water Supply Paper 115 (made in 1936, when many more wells existed) were omitted for two reasons:

1. Many of the surface elevations of wells listed there were found by the author to be in error, thus

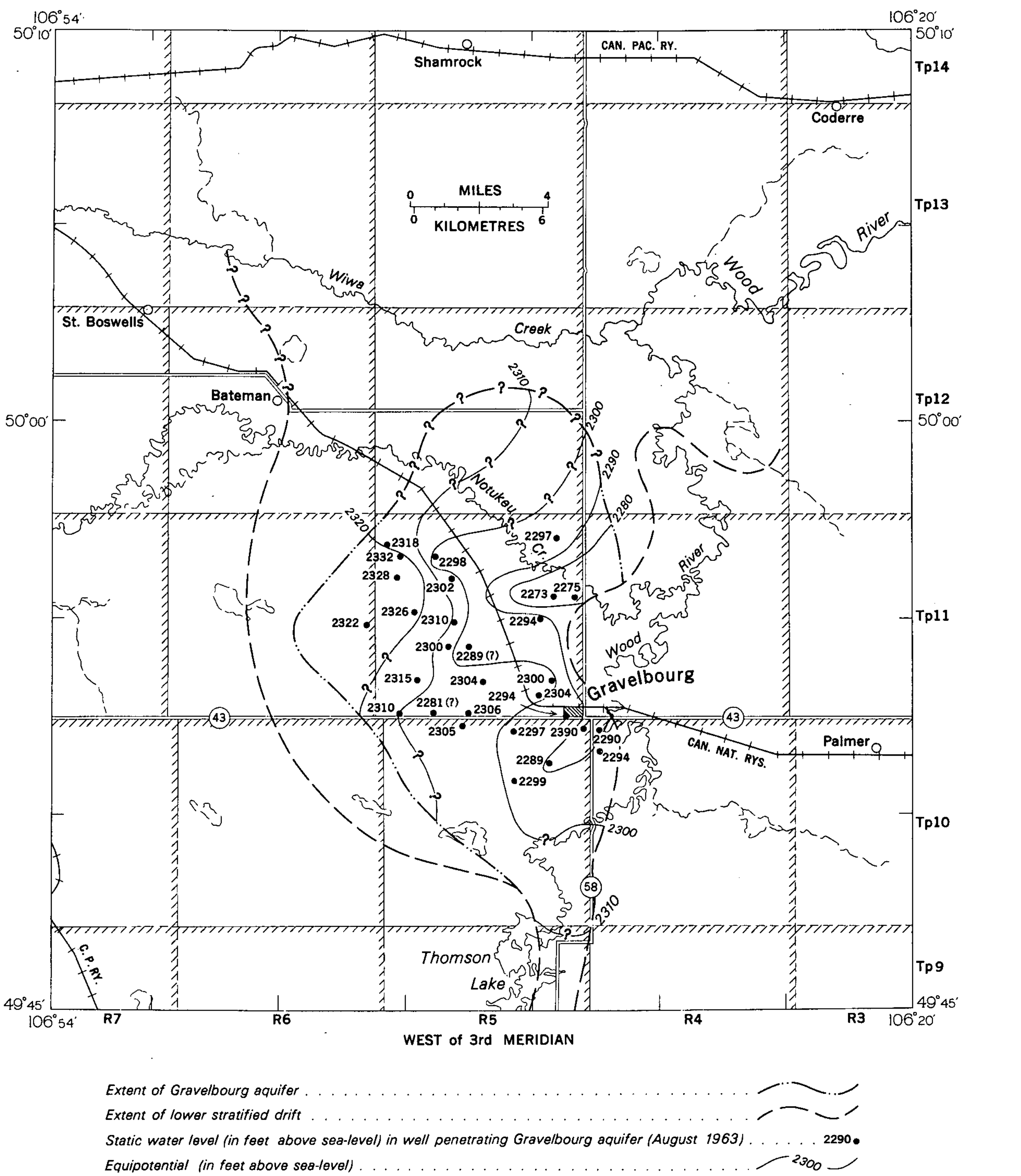



*Figure 14. Piezometric surface on the Gravelbourg aquifer.*

introducing an error into the static water level elevations.

2. It is desirable that the piezometric surface be representative of one point in time should long-term fluctuations be present (for example, a gradual lowering due to overpumping).

### Installation of Piezometers and Interpretation of Results

To investigate the validity of the assumption of horizontal flow in the aquifer and to determine the relation of the potential within the aquifer and to determine the relation of the potential within the aquifer to that in the underlying and overlying formations, the author installed a nest of five piezometers at Gravelbourg. The depths, spacing, and geology encountered are shown on Figure 15a. Figure 15b is a graph of the water level fluctuations in the piezometers from July 26, 1963 (shortly after installation) to June 20, 1964. Before attempting to interpret the results it is wise to look at the performance of the various piezometers. Numbers 3 and 4 show the most orderly behaviour; after installation their water levels rose until equilibrium was reached (about August 8, 1963 for 3, September 16, 1963 for 4). The recorded static water levels after these dates represent the potential in the aquifer at the base of each piezometer. Small-scale fluctuations occurring after the establishment of equilibrium are in response to changes in atmospheric pressure.

The water level in piezometer 1 began to rise from an initial elevation of 2,268.5 feet immediately after flushing ceased and it was still rising 11 months later (June 20, 1964). The latter part of this rise is shown on Figure 15b. Apparently the water level had not yet stabilized at that date.

Piezometer 5 showed a decline in water level until equilibrium was reached around September 16, 1963. The water left in the pipe by the flushing operation was obviously higher than the equilibrium water level in this locality and lower in the other three localities. The midwinter peak in the water level of this piezometer was due to a thaw. The subsequent fall of the water level is as yet unexplained.

Strange behaviour was shown by the water level in piezometer 2. It exhibited a gradual rise from July 26 to July 30, 1963 and then underwent a 6-foot drop overnight. It resumed the rise and apparently reached equilibrium about May 1964. The sudden drop may have resulted from some unsolicited tampering with the piezometer, or it may have been the result of a faulty seal at depth.

**Table X Water levels, Gravelbourg Piezometer Installation, October 15, 1963**

| Piezometer Number | Depth (feet) | Formation | Elevation of Water Level (ft. a.s.l.) |
|---|---|---|---|
| 1 | 300 | Bearpaw shale | 2,282.30 (rising) |
| 2 | 128 | Aquifer | 2,293.97 (stable) |
| 3 | 114 | Aquifer | 2,294.67 (stable) |
| 4 | 105 | Aquifer | 2,294.55 (stable) |
| 5 | 61 | Glacial till | 2,284.60 (stable) |

Some piezometer levels are summarized in Table X.

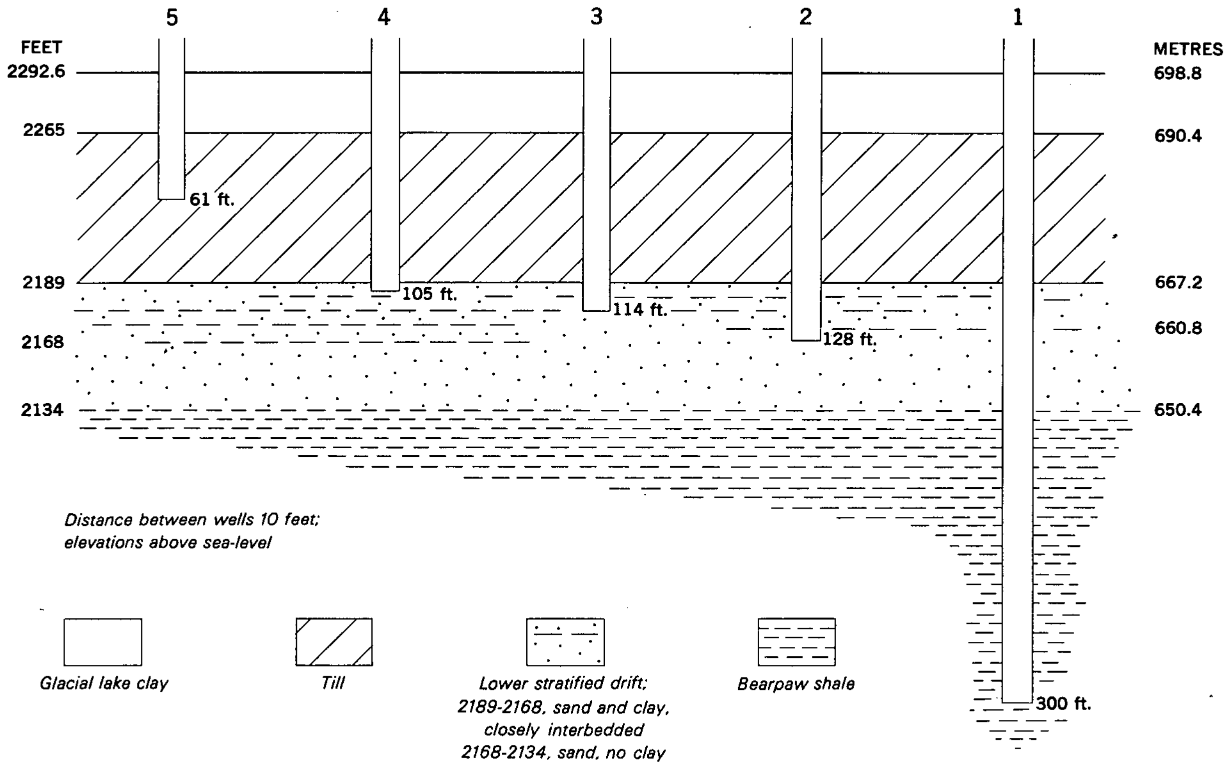
The potentials in the aquifer at depths of 105, 114, and 128 feet, as measured in piezometers 2, 3, and 4, are almost equal. The potential along this near-vertical line through the aquifer thus appears nearly constant. In the overlying till the potential as recorded by piezometer 5 is lower than that in the aquifer by about 9 feet.

The water level in piezometer 1 had not stabilized and no final conclusion could be drawn. Its water level, however, representing the potential in the shale, was still some 12 feet lower than that in the aquifer. The Bearpaw shale is relatively impermeable and any water existing in the formation is assumed to move through fractures. Because of the large difference in permeability between the shale and the aquifer, it is possible that the water in piezometer 1 is derived from leakage from the aquifer around the packer; if that is so, the water level will eventually assume the same elevation as in the other aquifer piezometers.

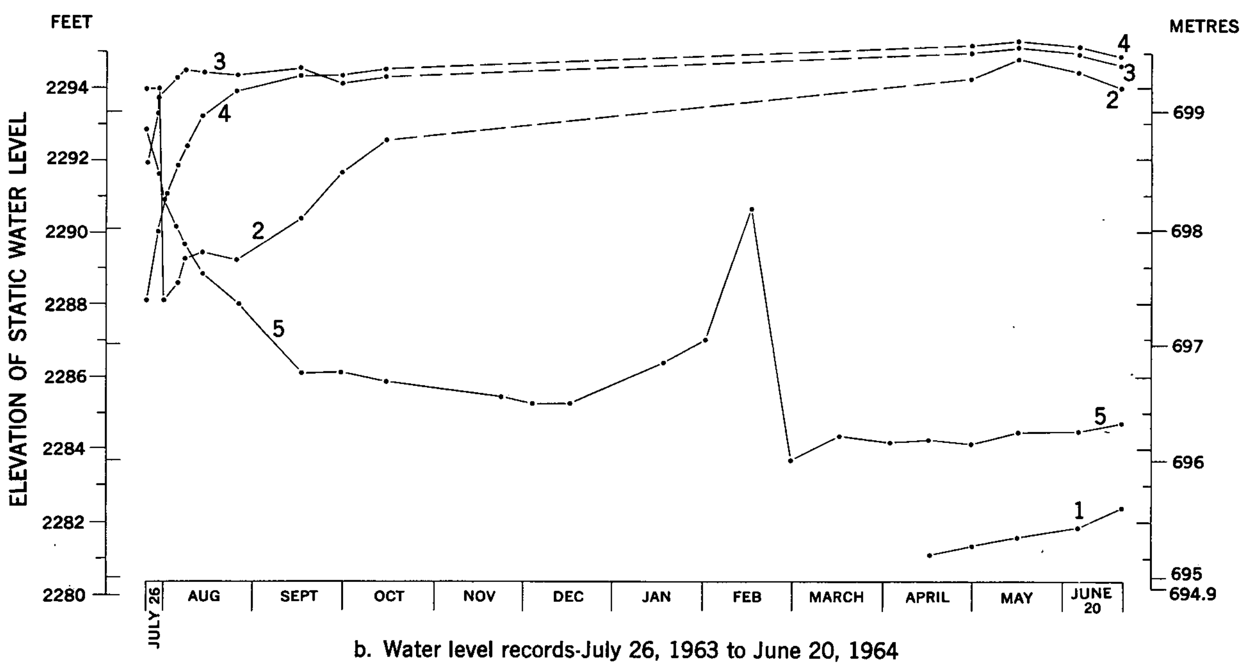
On the basis of the piezometer measurements it can be stated that the flow through the aquifer in the region of the piezometer installation is essentially horizontal, that leakage from the aquifer upward into the till does occur and that leakage downward into the shale is possible. Conversely, recharge into the aquifer from above is impossible and recharge from below unlikely in this part of the flow system.

### Analysis of Well Records

Plots of well depth versus depth to static water level for several topographic subdivisions of the Gravelbourg area, are shown on Figure 16. These plots can be used to distinguish between recharge areas and discharge areas because the potential decreases with depth in recharge areas and increases with depth in discharge areas (Figs. 11, 13).




a. Section, showing geology encountered




b. Water level records-July 26, 1963 to June 20, 1964

*Figure 15. Gravelbourg piezometer installation.*

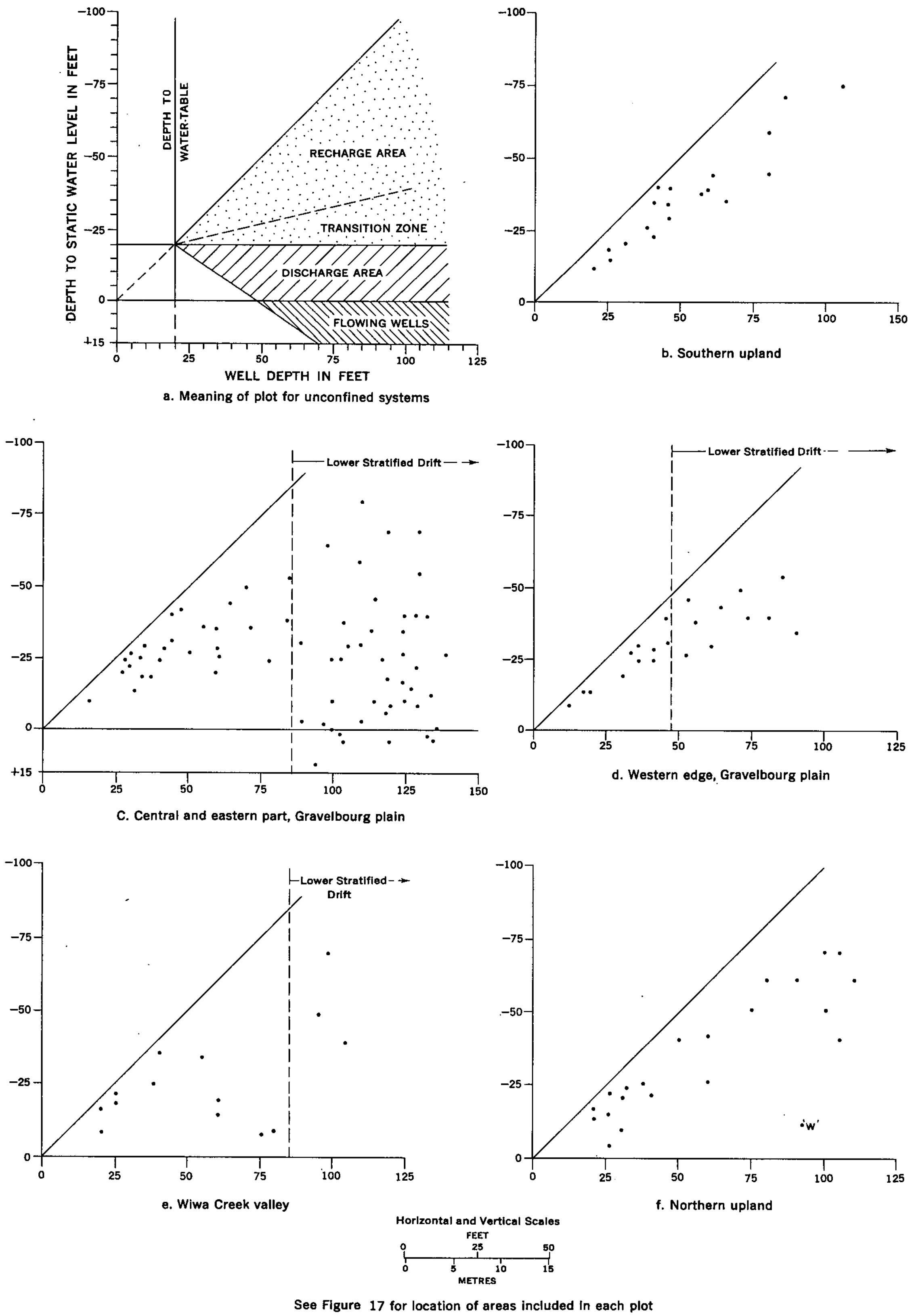



*Figure 16. Well depth vs. depth to static water level.*

There are three inherent assumptions in the plot:

1. The water table is equidistant below the surface over the area covered by each plot.

2. The wells act as 'open end' piezometers (see Fig. 13).

3. The flow system occurs in a homogeneous medium with no 'confined' aquifers present.

The explanation of the plot is shown in Figure 16a. Wells located in recharge areas will show greater depths to static water level as the well depth increases and will therefore plot upward and to the right in the indicated field. In discharge areas, deeper wells will exhibit higher water levels and will plot in the lower field. Flowing wells will, of course, plot below the x-axis (i.e., horizontal zero line), as shown on Figure 16a. Obviously, no point can exist to the left of the line representing the depth to the water table or above the upper 45° bounding line. Similarly, there is a lower bounding line, which depends on the vertical potential gradient in the discharge area.

Before noting the results, the validity of the three assumed conditions of the plot must be investigated. The first assumption, concerning the water table, although perhaps not completely valid, is certainly a very good approximation. The second condition, that the wells act as 'open end' piezometers, is true for cased wells and, as explained earlier, true to a certain extent for all wells in a discharge area. In a recharge area the assumption is not generally valid for wells with perforated casing (i.e., dug wells, wooden cribbing, etc.). However, in the Gravelbourg area, the nature of the glacial till in the recharge areas has a beneficial effect in that the till includes many small, thin sand and gravel lenses, and it is these lenses that are tapped by the wells. The static water level in a well is therefore a measure of the potential at the base of the well in the sand lens that is being tapped. These sand lenses are not generally interconnected so it is valid to view the glacial till on a large scale as homogeneous, and the static water levels as representative of the potential at a point in the system. The third assumption of a homogenous medium with no 'confined' aquifers is thus upheld in the glacial till, but is clearly violated in the wells penetrating the Gravelbourg aquifer.

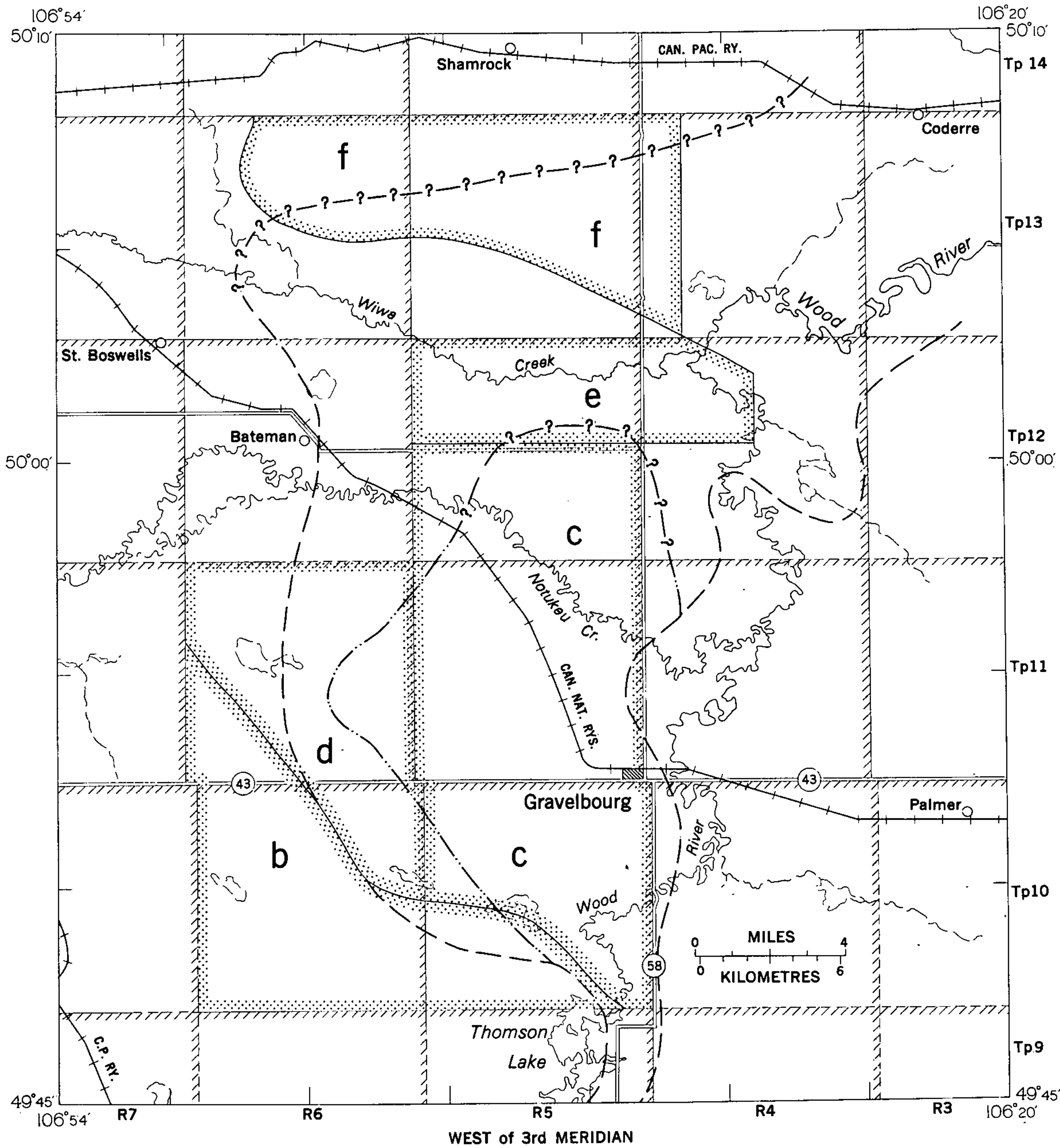
Figure 17 shows the location of the areal subdivisions used in the plots of Figure 16. Figure 16b shows that the *southern upland* (denoted by 'b' on Figure 17) is a recharge area with the wells plotting in a very narrow field near the upper bounding line. This area consists of glacial till from the surface right down to bedrock.

Figure 16d shows that the *western edge of the Gravelbourg plain* (denoted by 'd' on Figure 17) is also a recharge area. An interesting feature of the plot is that the points begin to veer away from the upper boundary line at depth. This is indicative of a relative decrease of the vertical component of the potential gradient, owing to the formation of a horizontal component of the gradient or, in other words, the beginning of a horizontal flow component. Keeping in mind that the lower stratified drift was encountered at a depth of 37 feet in hole B (Fig. 7), it is clear that the lower stratified drift, including the Gravelbourg aquifer which thickens to the east, is recharged in this area. The piezometric surface (Fig. 14) also showed this region to be the source of the horizontal flow through the aquifer.

The conditions of the region underlain by the *main body of the Gravelbourg aquifer* are shown in Figure 16c. Once again the points show the existence of recharge from the surface and the beginning of a horizontal flow component at depths of 60 to 85 feet. Below 85 feet, however, the points represent wells penetrating the lower stratified drift (in most cases, the aquifer itself). Since this aquifer is in effect a 'confined' aquifer exhibiting horizontal flow, the position of the point on the plot actually depends on the location of the well in the piezometric surface gradient and not on the depth of the well. In other words, assumption 3 is violated. The plot shows heads in the glacial till (between 20 and 85 feet below surface) to be lower than some of those in the aquifer and higher than others. The presence of a lower head indicates upward leakage from the aquifer into the till, as indicated in the discussion of the Gravelbourg piezometer installation; the presence of a higher head in the till indicates recharge of the aquifer from above. This is in the western part as seen in Figure 16d.

Surficial evidence (*see* later section) indicates that the *Wiwa Creek valley* (Fig. 16e) is a discharge area and the diagram confirms this, because the wells 60 to 85 feet deep have higher heads (i.e., lower depth to static water level) than the shallower wells. The lower stratified drift was encountered at a depth of 82 feet in hole D (situated in the valley) and it is seen that the three wells on Figure 16e that penetrate the lower stratified drift do not plot as discharge area wells. In fact, their heads fall into line with the piezometric surface on the aquifer. This is interpreted as an indication that the groundwater discharged into Wiwa Creek valley is part of a shallow flow pattern confined to the glacial till and that horizontal flow exists in the lower stratified drift even outside the confines of the aquifer itself. Although horizontal flow is predominant in the lower stratified drift at this point, other considerations suggest minor upward movement from the formation into the shallower flow system.

*The northern upland* is a recharge area, as indicated by




| | |
|---|---|
| *Southern upland* | b |
| *Central and eastern part, Gravelbourg plain* | c |
| *Western edge, Gravelbourg plain* | d |
| *Wiwa Creek valley* | e |
| *Northern upland* | f |
| *Extent of lower stratified drift* | (dashed line) |
| *Extent of Gravelbourg aquifer* | (dash-dot line) |

*Figure 17. Location of areas used in plots of well depth vs. static water level (Fig. 16).*

Figure 16f, showing the characteristic lessening of potential gradient with depth. The one well 'w', which plots in the discharge field, may possibly be explained by a till well that cuts more than one sand lens (i.e., its effective well depth is much less than plotted), or by a well in a local discharge area on the upland.

## HYDROGEOCHEMISTRY

### Nature of Groundwater

Chemical analyses of 38 water samples taken from the Gravelbourg area are given in Appendix II; the locations of the wells from which the samples were taken and the water source are shown on Figure 18.

The hydrogeochemistry of water from the various geologic formations is shown diagrammatically on Piper trilinear plots (Hem, 1959, p. 182); the hydrogeochemistry of water from glacial till and surficial glacial lake sands is shown on Figure 19. The points indicate a wide spread on the cation triangle with Mg and Ca generally nearly equal in abundance (the Mg/Ca ratio averages 120). There are two groupings of points, one with high Na and one with low Na. On the anion triangle, the points plot along the $SO_4$–$HCO_3$ edge with the Cl content seldom exceeding 10 per cent. When the points are projected onto the upper field a large scatter is observed.

Some light is thrown on the nature of the scatter by a study of Figure 20 which has the same plot as Figure 19, but with the total dissolved solids (TDS) of each sample noted. From the cation triangle it can be seen that the low Na waters are also low in TDS whereas the high Na waters are high in TDS. The approximate position of the 1000 ppm contour is shown. Similarly on the anion triangle the waters high in $HCO_3$ are seen to be low in TDS, whereas those high in $SO_4$ are, with few exceptions, high in TDS. The separation of points on the basis of dissolved solids is also clear on the diamond-shaped field. The conclusion to be drawn from these two diagrams is that the relative ion concentrations in water from glacial till are related to the quantity of dissolved solids.

What then causes the variation in TDS? Comparison of Figures 18 and 19 will not reveal any correlation of chemistry with location for till samples. This is to be expected, as most of the till wells are in recharge areas and are of various depths. No straightforward relation exists between well depth and TDS. In a very general way, the value of the range of concentrations increases with depth, but the relation is far from linear.

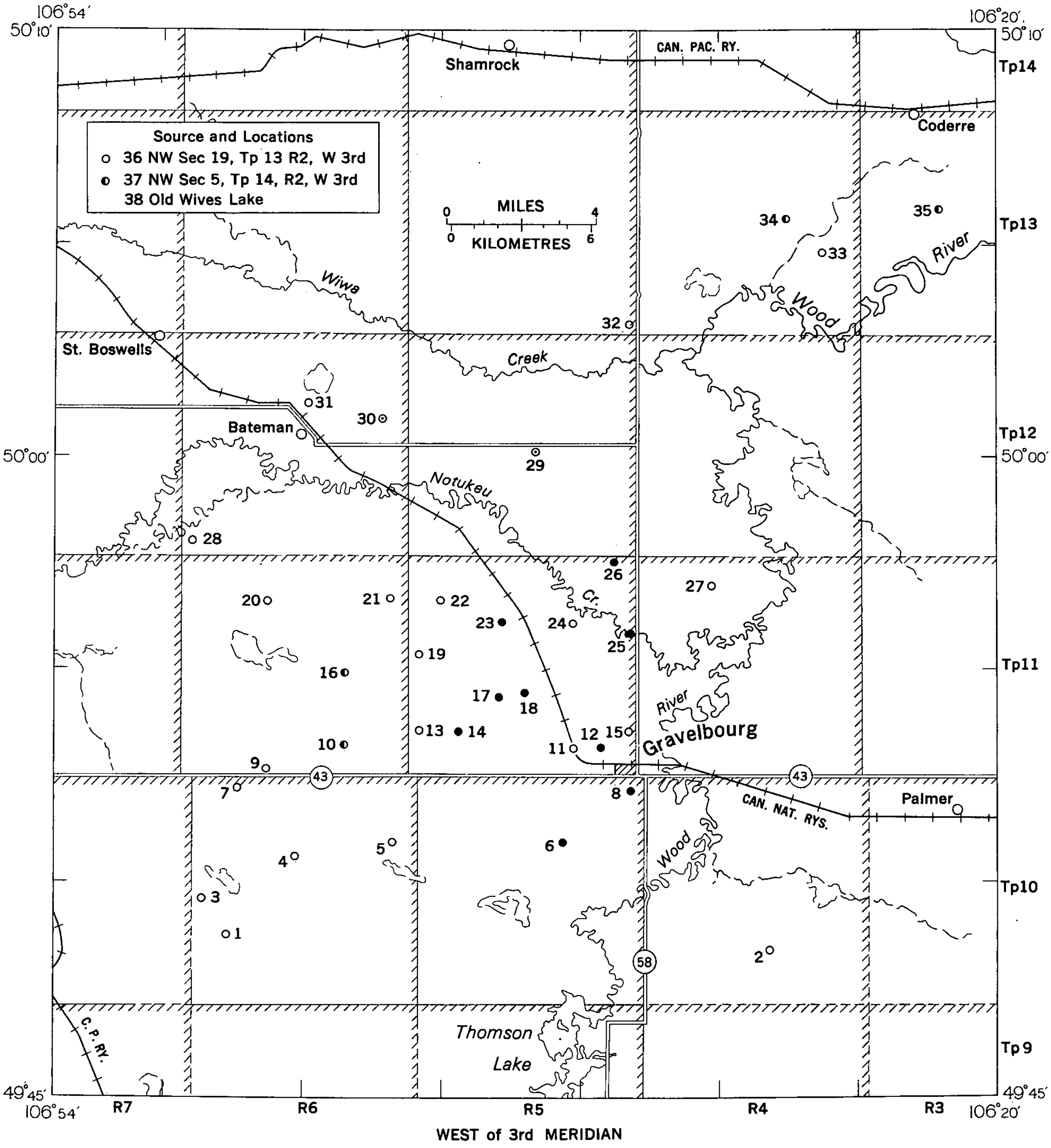
The wide range of chemical compositions in near-surface groundwaters has been observed throughout the Canadian prairies. At least two contributing factors have been recognized. Toth (1963) has explained one situation that occurs in rolling topography: "As a result of the local [flow] systems, alternating recharge and discharge areas are found across a valley. This means that the origins of waters obtained from closely located places may not even be related. Rapid change in chemical quality may thus be expected." The second and more general cause of the phenomenon, however, is the climatic zonation as described by Schoeller (1959). He noted that a major feature of arid-zone hydrogeology is the variety of the types of water that may be found, and the close proximity of the physical conditions productive of such variety.

In a semi-arid region, such as southern Saskatchewan, low rainfall and high evapotranspiration tend to concentrate salts in the soil and soil water. Schoeller stated: "The soil water thus becomes progressively more mineralized and the next fall of rain of sufficient magnitude for deep infiltration carries the concentrated solutions in more or less diluted form from the soil to the water table. It will readily be appreciated that the greater the interval between infiltrating precipitations replenishing the water table, the sparser the rainfall in general, and the higher the temperature and the deficit in atmospheric saturation, the higher will be the mineralization of the waters of infiltration." It is also clear that inhomogeneous soils and local variations in temperature, rainfall, and evapotranspiration will tend to produce great variations in the chemistry of the percolating waters.

Climatic zonation also affects the chemical composition of the water. In arid zones it is common to have $Cl>SO_4>HCO_3$ and for Mg, Ca, and Mg/Ca to increase as the $SO_4$ content increases. Geological factors, of course, modify these generalized patterns so that in the Gravelbourg area excessive selenite in the sediments has resulted in high $SO_4$ values at the expense of Cl, and base exchange of Ca and Mg in the water for Na in the clay has tended to increase the Na content of the groundwater.

The hydrogeochemistry of nine samples from the Gravelbourg aquifer is shown in Figure 21. The waters are high in Na and $SO_4$ and possess TDS values ranging from 2574 to 5207 ppm. This composition corresponds to that of the highly mineralized till waters (see Figs. 19 and 20) and also to water from the silty clay phase of the lower stratified drift (see Fig. 22). The Old Wives Lake analysis is included for comparison.

No wells produce from the Bearpaw Formation in the Gravelbourg area; it was felt, however, that the hydrogeochemistry of the formation should be noted. A Piper




## SOURCE OF WATER

*Glacial lake sand* . . . . . . . . . . ⊙

*Glacial till* . . . . . . . . . . o

*Silty clay phase of lower stratified drift* . . . . . . . . ◐

*Gravelbourg aquifer* . . . . . . . . . . ●

*Sample numbers (see Table XIV in Appendix II)* . . . 14

*Figure 18. Locations of hydrogeochemical samples.*

plot of five analyses from Bearpaw wells in other parts of the Old Wives Lake drainage basin is shown in Figure 23. The major feature of Bearpaw water is the complete dominance of the Na anion. This is due to base exchange between the water and the shale. The Na in the montmorillonite of the shale is replaced by Ca and Mg from the water, thus increasing the Na concentration of the water. Schoeller (1959) has defined a base exchange index (ieb) for groundwaters such that:

$$\text{ieb} = \frac{\text{Cl} - (\text{Na} + \text{K})}{\text{Cl}}$$

when Na, K in the water are exchanged for Mg, Ca in the soil or rock; and

$$\text{ieb} = \frac{\text{Cl} - (\text{Na} + \text{K})}{\text{SO}_4 + \text{HCO}_3 + \text{NO}_3}$$

when Mg, Ca in the water are exchanged for Na, K in the soil or rock. All concentrations are expressed in epm. As the exchange becomes more complete, the ieb (using the second definition) will approach -1.00. The ieb of the five Bearpaw samples shown in Figure 23 varies from -0.87 to -0.99.

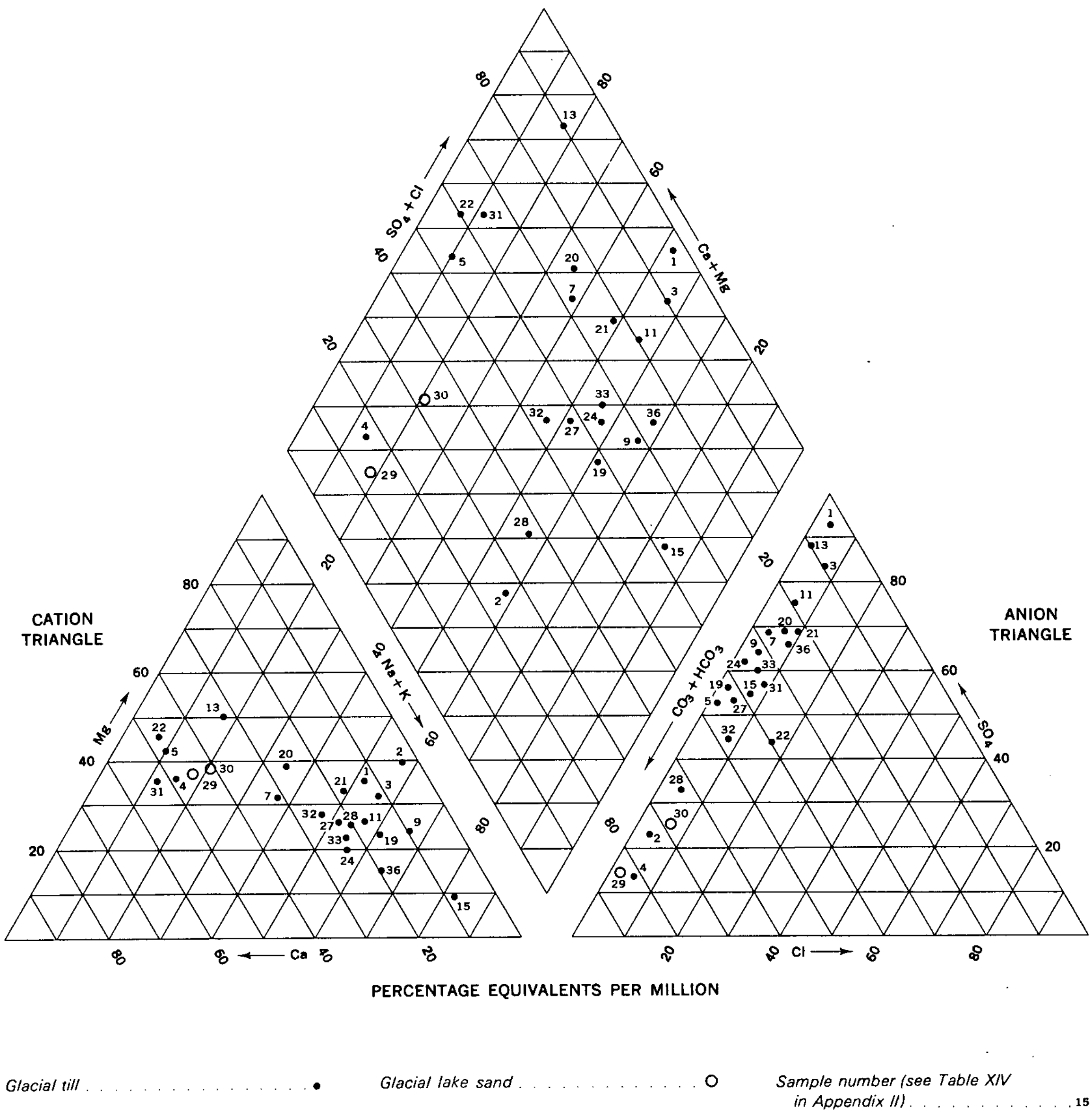



*Figure 19. Hydrogeochemistry of water from glacial till.*

### Correlation with Flow Pattern

In regions of humid climate the fact that the value of TDS increases with the length of flow path can be used to trace groundwater flow patterns, and it was the author's initial intention to utilize the Gravelbourg geochemical analyses in this way. As demonstrated in the foregoing section, however, the varied nature of the chemistry of near-surface waters in semi-arid regions precludes the straightforward application of this method. Nevertheless, some conclusions can be drawn.

The areal pattern of total dissolved solids for the various formations is indicated in Figure 24. Samples 10 and 22 have been omitted because their high nitrate content indicates farmyard contamination. Samples 33 to 37 were taken outside the map-area.

For the area underlain by the lower stratified drift, it is clear from the values shown on Figure 24 that water from shallow wells in glacial till, silty clay, and glacial lake sand have a lower value of TDS than the water found in the aquifer. This is to be expected as the 'well depth versus depth to static water level' plots showed that, over the larger part of the area, recharge enters the aquifer from overlying formations.

A comparison of the TDS values, shown by the nine

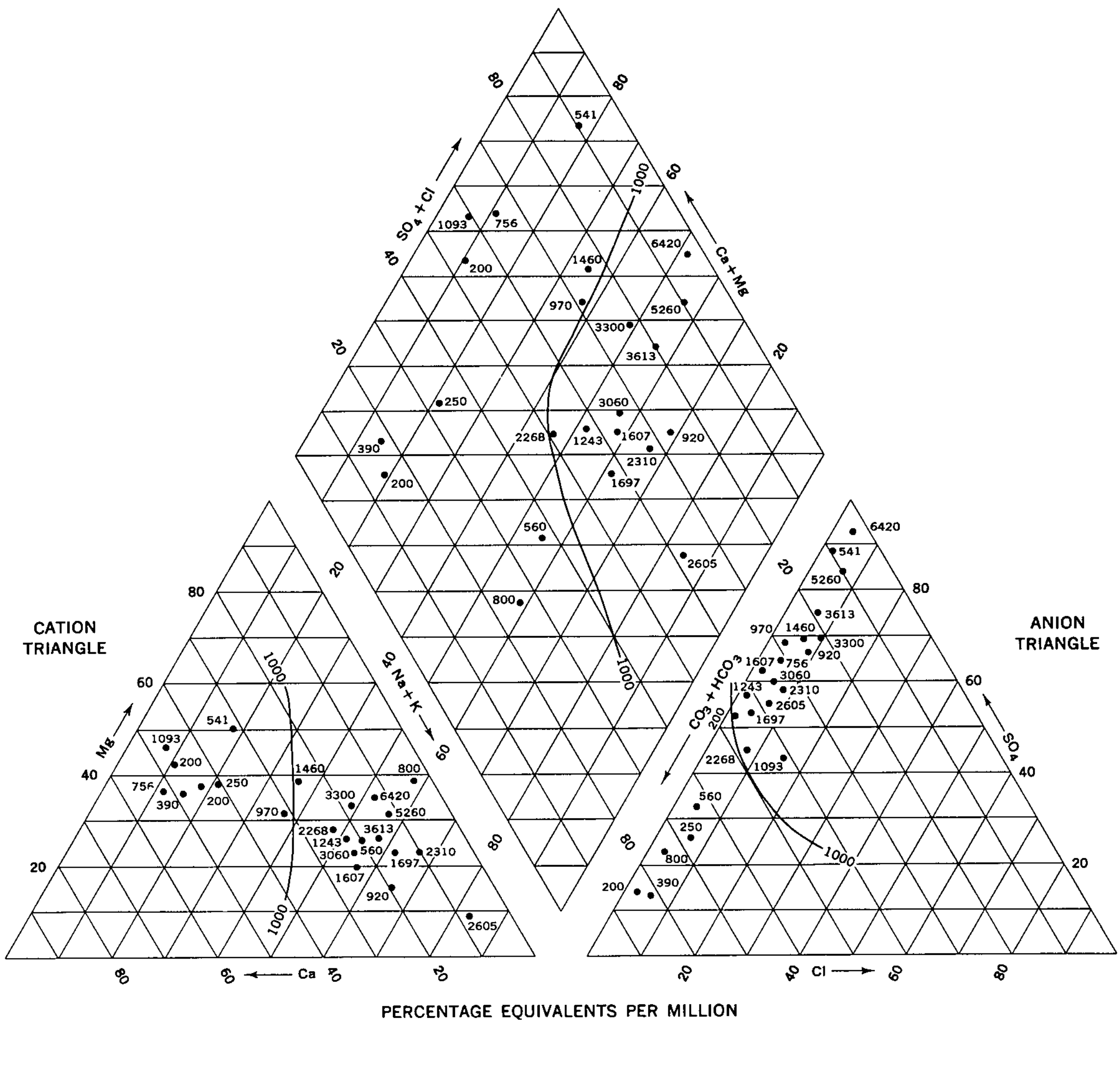



*Figure 20. Relation between total dissolved solids and chemical composition of water from glacial till.*

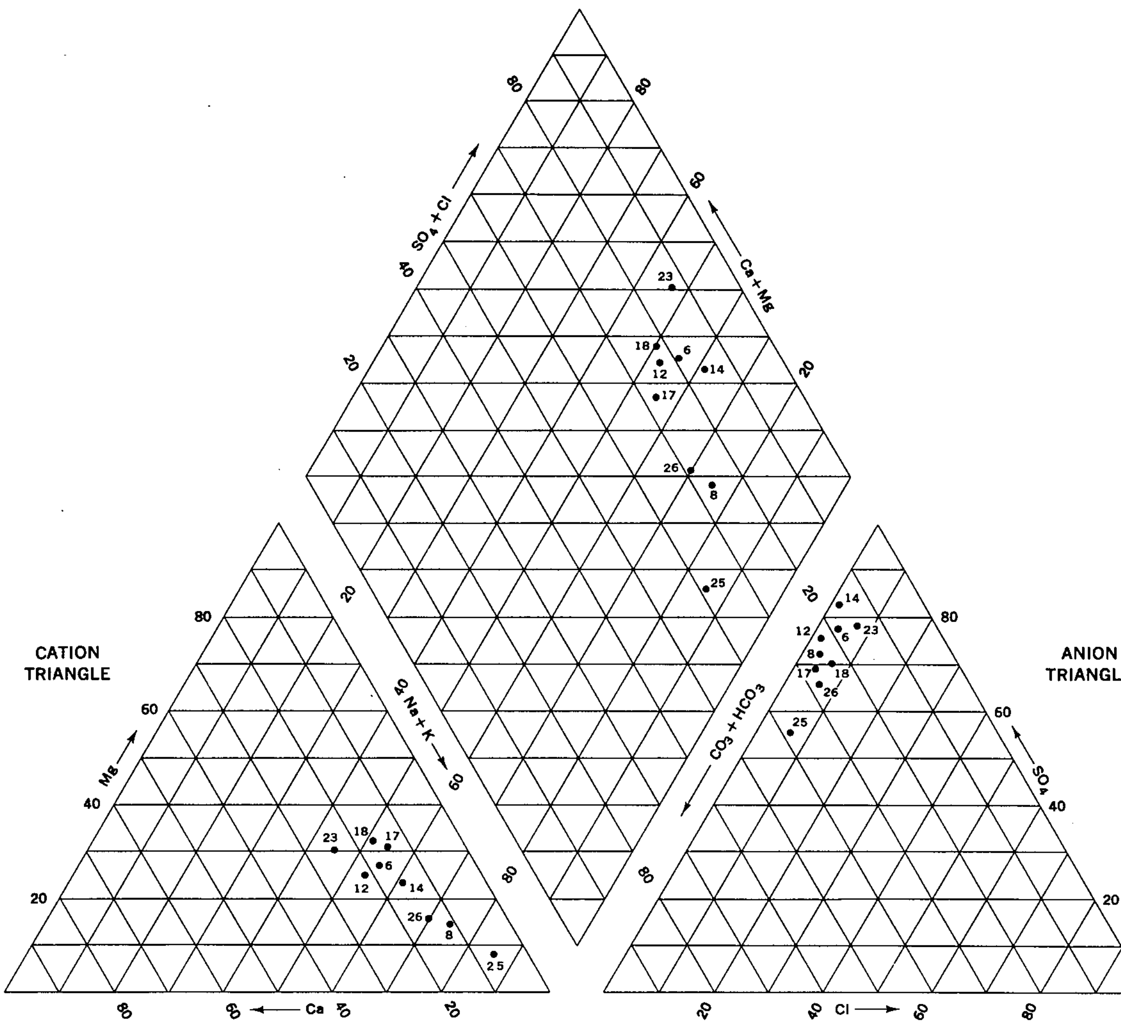
aquifer samples, with the piezometric surface on the aquifer (Fig. 24) shows that, instead of an orderly increase in the direction of flow, the pattern of TDS values appears to be random. For example, between the 2300-and 2290-foot equipotentials the full range of concentrations from 2574 to 5207 ppm is represented. This is a further reflection of the varied chemical composition of the recharging water.

Because of the complete dependence of the nature of the chemical composition on the degree of mineralization, areal plots of other index constituents and ratios also show random patterns.

### Tritium Analyses

The feasibility of dating water by analysing its tritium[1] content was first suggested by Libby (1953). The method has since been applied successfully many times to groundwater, and if representative samples of a given flow system are chosen, the method offers another hydrogeochemical correlative technique.

[1]Tritium is the radioactive isotope of hydrogen. It has an atomic number of 1 and a mass number of 3 (i.e., one tritium atom consists of 1 electron, 1 proton, and 2 neutrons).




PERCENTAGE EQUIVALENTS PER MILLION

*Sample number (see Table XIV in Appendix II)* . . . . . . . . •12

*Figure 21. Hydrogeochemistry of water from Gravelbourg aquifer.*

Tritium in rainwater comes from two sources:

1. Natural cosmic-ray tritium from the atmosphere, and
2. Artificial tritium released into the environment by nuclear explosions.

The tritium is introduced into the surface water–groundwater system by rainfall and leaves the system by:

1. Radioactive decay;
2. Discharge of river water of given tritium concentration; and
3. Evaporation of water of given tritium concentration.

The age of a given groundwater sample may thus be determined from the lag in appearance of bomb tritium injections, or if it has been in the groundwater flow system longer than the period during which bomb tritium has been released, from the extent of radioactive decay of natural tritium (Brown, 1961).

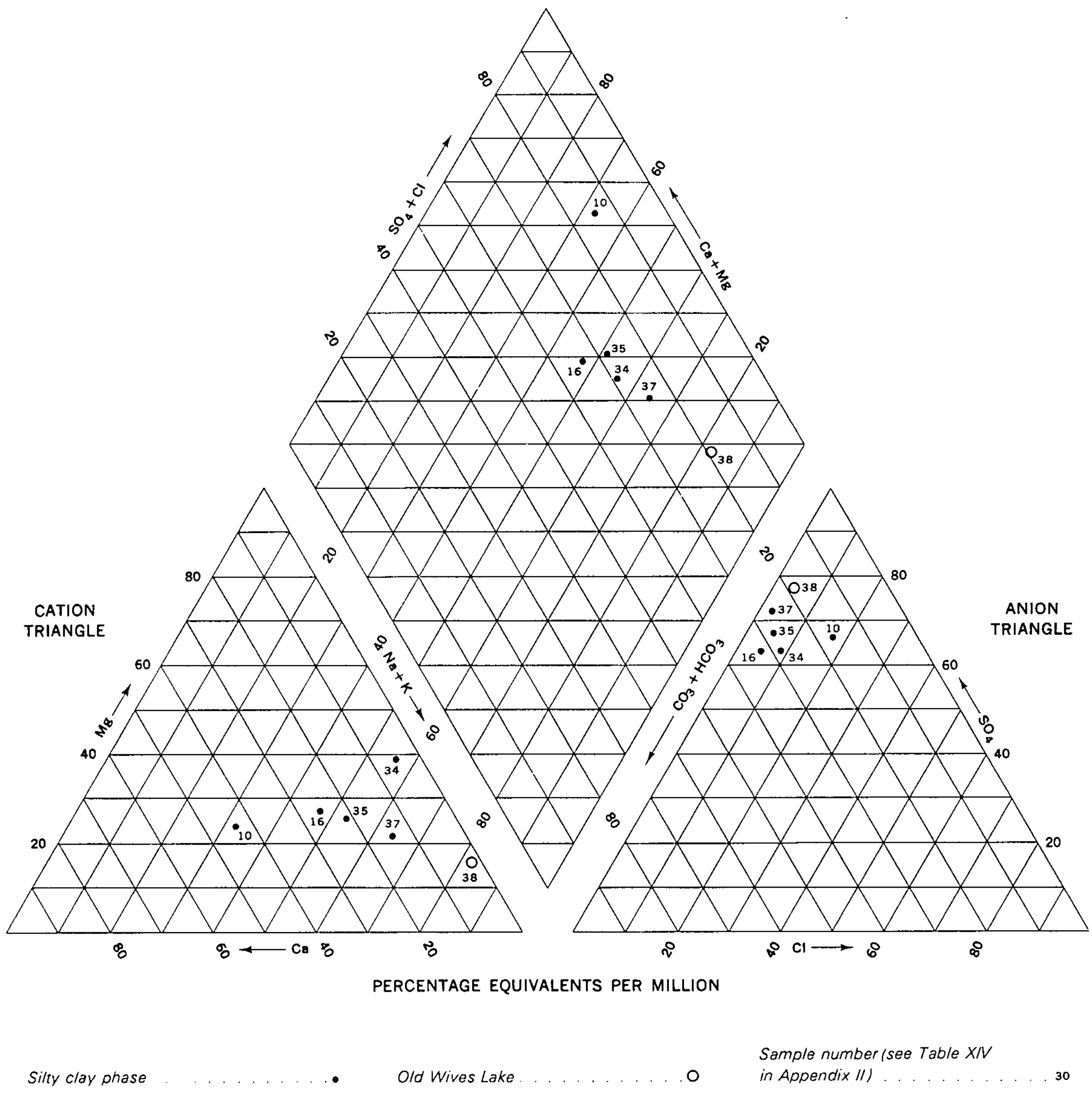



*Figure 22. Hydrogeochemistry of water from silty clay phase of lower stratified drift.*

Tritium concentrations are usually expressed in terms of tritium units (T.U.), where 1 T.U.= 1 tritium atom per $10^{18}$ hydrogen atoms. The tritium concentrations in August 1963 of five groundwater samples from the Gravelbourg flow system are listed in Table XI. Figure 18 shows the location of the wells from which the samples were taken and denotes the source of the water. On the basis of the tritium concentrations, the estimated date of original precipitation (i.e., the age of the water) is given on Table XI for each sample.

Before interpreting these results, a few comments are necessary:

1. The indicated dates are based on records of tritium concentrations as measured in precipitation at Ottawa, Ontario, and applying appropriate decay factors to obtain the present-day Gravelbourg values. Ottawa is the closest Canadian station with the longest period of record (1953 to present). Good records are also available at Chicago, but it is felt that Saskatchewan more closely resembles Ottawa than Chicago, where low tritium evaporate from Lake Michigan may affect results. Good correlation exists between Saskatoon data and Ottawa data for the period 1959-62, thus lending confidence to the use of the Ottawa data for the earlier period (Brown, R.M., pers. com., Nov. 26, 1963).

2. The ages quoted for samples 8 and 9 are based on decay from a natural cosmic-ray tritium level of 15 T.U. (Brown, R.M., pers. com., Nov. 26, 1963).

3. Alternative dates are given for samples 7, 16, and 25, because without more complete sampling, it cannot be

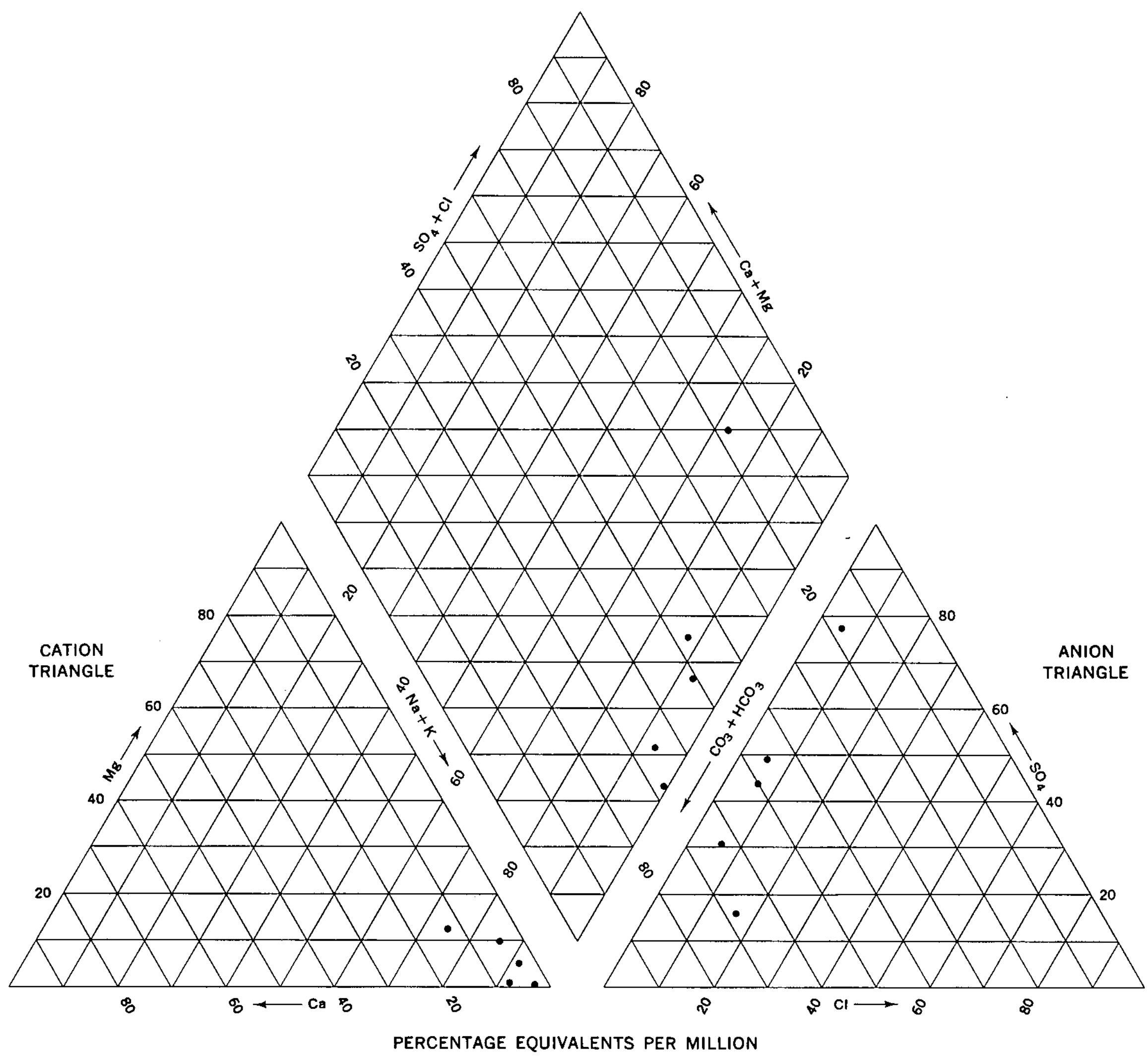



*Figure 23. Hydrogeochemistry of water from Bearpaw shale.*

determined from which bomb-induced tritium peak the present concentration has descended.

4. In a situation such as the Gravelbourg flow system, each sample may represent a mixture of waters of many different sources and each age determined, therefore, represents an average of the transit times of many flow paths.

The general nature of the Gravelbourg flow system, as it

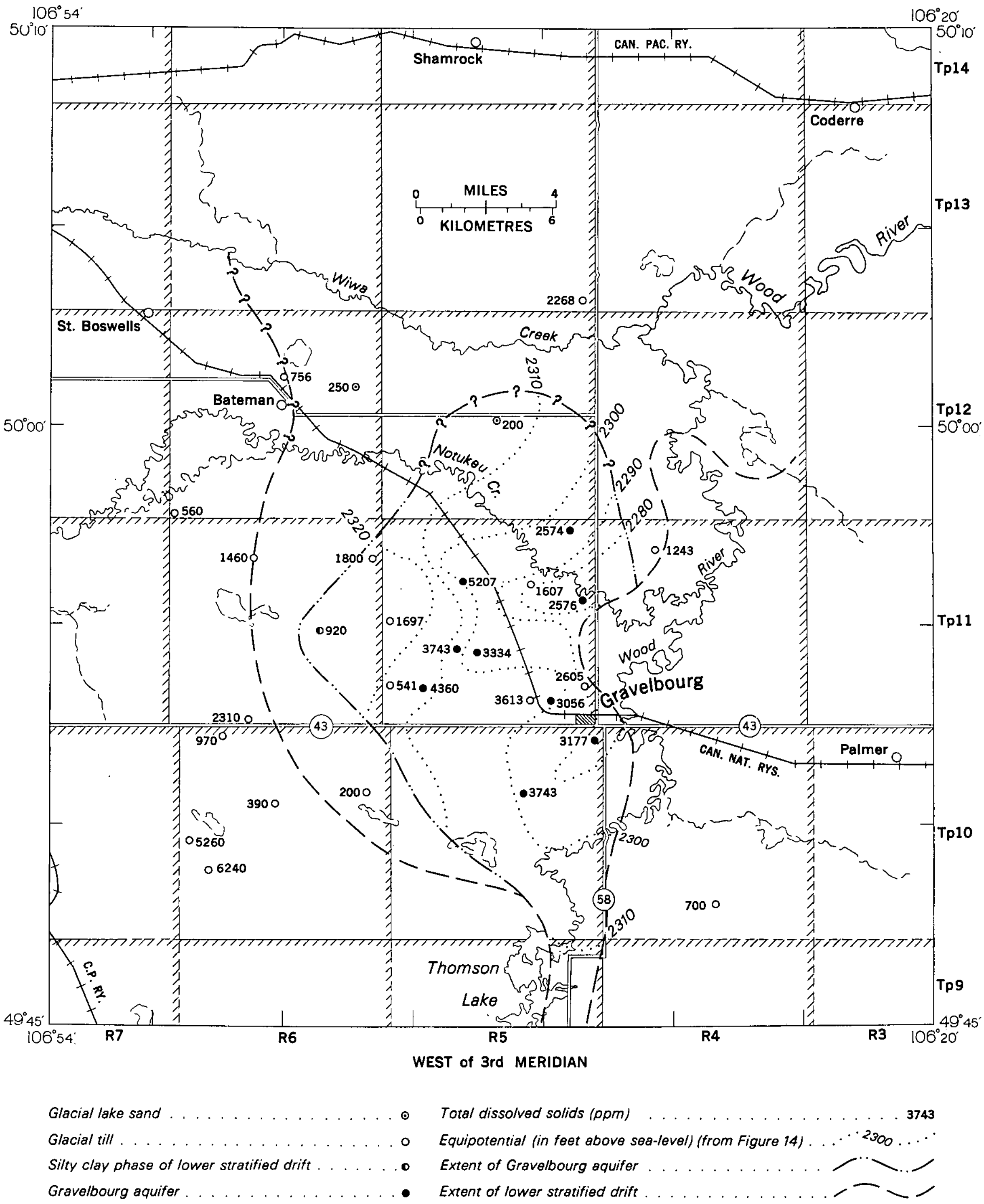



*Figure 24. Areal pattern of total dissolved solids.*

**Table XI Tritium Concentrations of Groundwater from Gravelbourg Flow System**

| Sample Number | Location | Depth of Well (feet) | Aquifer | Tritium Concentration August, 1963 (T.U.) | Estimated Date of Precipitation |
|---|---|---|---|---|---|
| 7 | NW-32-10-6-W3 | 32 | Till | 106. | Alternatives:<br>summer 1954<br>spring 1956<br>summer 1957<br>winter 1959-60<br>winter 1960-61 |
| 9 | SW-4-11-6-W3 | 100 | Till | 3.0 | 1935 |
| 16 | NW-14-11-6-W3 | 45 | Silty clay | 9.2 | Alternatives:<br>summer 1953<br>autumn 1955 |
| 8 | NE-36-10-5-W3 | 176 | Gravelbourg aquifer | 3.6 | 1938 |
| 25 | NE-24-11-5-W3 | 120 | Gravelbourg aquifer | 11.4 | Alternatives:<br>summer 1953<br>autumn 1955 |

Tritium analyses by R.M. Brown, Environment Research Branch, Atomic Energy of Canada, Ltd., Chalk River, Ontario.

has heretofore been described, is further corroborated by the tritium ages. Samples 7 and 16, from shallow wells in recharge areas, exhibit more recent water than does either sample 9 (from a deep well in a recharge area) or sample 8 (from the Gravelbourg town well, which taps the Gravelbourg aquifer near its downstream end). The age given for sample 25, also from the aquifer, appears to be much too recent.

It is necessary to further examine these results, sample by sample, in order to discover all their quantitative ramifications. Samples 7, 9, and 16 all represent waters that have reached their present position by vertical percolation from surface recharge areas through glacial till. Their ages suggest a macroscopic vertical velocity of about 3 to 10 ft/year. The vertical gradient in recharge areas in glacial till (Fig. 16b) is in the order of 0.66 ft/ft. A simple expression for the calculation of the vertical permeability Kv is:

$$K_V = 6.25\, a\, v/i$$

where $K_V$ = vertical coefficient of permeability (gal/day/ft$^2$)

$a$ = porosity (fraction)

v = macroscopic vertical velocity (ft/day)

i = hydraulic gradient (ft/ft).

Assuming a porosity of 40 per cent for the glacial till, the above expression gives a vertical permeability in the order of 0.05 to 0.1 gal/day/ft$^2$. This is considerably lower than the values of 1 to 5 gal/day/ft$^2$ suggested by the pump test at Gravelbourg and quoted in a later section. Considering both pump test and tritium evidence, it appears that the order of magnitude of the vertical permeability through glacial till in the Gravelbourg area is 0.05 to 5.0 gal/day/ft$^2$.

If the horizontal permeability of the Gravelbourg aquifer is of the order of 100 gal/day/ft$^2$, as given by the pump test, and the hydraulic gradient is about 5 ft/mile, as shown by the piezometric surface (Fig. 14), the velocity of horizontal movement within the aquifer is only a few feet per year. This suggests that it would have taken several hundred years for the water from the Gravelbourg town well (sample 8) to have reached its present position by horizontal flow through the aquifer from the recharge area in the western part of the plain. The age given in Table XI thus appears to be exceptionally low. A possible explanation lies in the fact that the Gravelbourg aquifer is "leaky" (see pump test curves, Figs. 29 and 30) and under the influence of pumping, a local downward gradient is set up around the well field, thus reversing the natural upward artesian gradient. The water is thus a mixture of older aquifer water and induced downward leakage. The induced downward leakage, having a 'post-bomb' source and a short path to travel under high gradients, will have a tritium concentration many times higher than that of the aquifer water. Relatively small quantities of downward leakage, when mixed with larger quantities of low concentration aquifer water, could thus lead to anomalously high tritium concentrations. Thus the quoted age appears more reasonable.

No such clear-cut explanation is available for the tritium data of sample 25. The water is clearly not being wholly supplied by the aquifer, yet all other evidence (piezometric water level, etc.) points to the well having a hydraulic connection with the aquifer. The most logical interpretation is that the well takes most of its water from a fairly near-surface horizon in the till or silty clay, which is recharged by downward percolation.

The author feels that, although tritium data can be a useful correlative tool for the *confirmation* of groundwater flow patterns, the many opportunities for misinterpretation, particularly in trying to decide what each sample actually represents, relegate this method to a secondary role in the actual *tracing* of the flow system. Its main importance may well be in the determination of additions to the flow system.

## SURFICIAL EVIDENCE OF DISCHARGE AREAS

In humid areas the topographic lows are almost always occupied by surface water in the form of streams and lakes, so that groundwater discharge invariably takes the form of a component of their flow. In arid and semi-arid regions, however, and particularly in glacial terrains having disorganized or closed drainage, intermittent streams and intermittent depressional sloughs are common and the upward rising groundwater is discharged into the air by evapotranspiration during much of the year. Because of the high degree of mineralization in arid-zone groundwaters, a constant supply of salts is provided to the discharge area, and when evaporation occurs these are left behind as a saltcake. In southern Saskatchewan the salt crust is generally composed of $Na_2SO_4$, reflecting the nature of the chemical composition of the groundwater. The local name for the $Na_2SO_4$ crusts is 'white alkali.'

This phenomenon also accounts for the high degree of mineralization in permanent sloughs and closed-basin lakes. In many lakes in Saskatchewan, concentrations have become so high that deposition of $Na_2SO_4$ on the lake bottom has reached considerable proportions and the salt is being mined economically.

Meyboom (1962) has suggested that the disparity between the degree of mineralization of surface water bodies fed in part by groundwater and those having surface runoff as their only source is sufficient to enable the use of TDS as a criterion in deciding if groundwater discharge is present.

A consequence of the high salt content in discharge-area soils is the establishment of salt-tolerant plants entirely different from the usual prairie vegetation. These plants are known as halophytes and the presence of a halophytic ecological association is therefore indicative of a groundwater discharge area. Meyboom (1962) has given a systematic description of the various types of 'groundwater outcrops' that may be identified by their topography and vegetation.

In the Gravelbourg area, two regions show surficial evidence of groundwater discharge. The first is Wiwa Creek valley in the northern part of the area and the second is a string of depressional sloughs along the southwestern edge of the Gravelbourg plain, at the base of the southern upland. These areas are shown on Figure 2, where their relation to the topography can best be appreciated.

Temporary sloughs in the Gravelbourg area occupy small depressions and are characteristically intermittent. Upon evaporation a saltcake remains and the highly salt-tolerant *Suaeda depressa-Salicornia rubra* association thrives. In Wiwa Creek valley many patches of saltcake showing the above plant association are present, but over much of the valley upward movement of groundwater is indicated by the abundant growth of *Distichlis stricta* (salt-grass), a well known halophyte, which has also been described by Robinson (1958) as an active phreatophyte.

Neither the piezometric analyses nor surficial evidence shows that Notukeu Creek or Wood River receives groundwater discharge other than from its immediate banks. On the contrary these streams may be influent, as suggested by recorded water losses between gauging stations on Notukeu Creek. It is unlikely that they play any significant role in the groundwater flow system in this area.

## THEORETICAL APPROACH

Tóth (1962, 1963) has expanded the original theoretical treatment of regional groundwater flow (Hubbert, 1940), in the consideration of small drainage basins. He has studied, by means of two-dimensional mathematical models, the flow between a water divide and an adjacent valley bottom for:

1. A water table that slopes linearly outward from the bottom of the valley; and

2. A water table that follows a sine curve oscillating about a line sloping linearly outward from the bottom of the valley.

In both, the model is bounded by two theoretically impermeable boundaries extending vertically downward from the stream and the water divide, and by a horizontal impermeable boundary at the base.

When these boundary conditions are applied to the general solution of the two-dimensional Laplace equation (which is applicable for the calculation of the potential field under steady-state conditions), an expression for the potential at any point is derived.

The resulting flow patterns for (1) with the impermeable base at two different depths are shown in Figure 25 (after Tóth, 1962). It should be noted that although the equipotential lines are accurately constructed, the flow lines do not have quantitative significance. The slope of the water table is of the order encountered in small prairie basins. Figure 25 should be compared with Hubbert's flow pattern as shown on Figure 11.

Figure 26 (after Tóth, 1963) shows the flow patterns for (2) for two different inclinations of the sine curve, and a depth to the impermeable boundary of 1,000 feet. An exaggerated vertical scale is used. It should also be noted that "..the potential distribution along the theoretical surface, although identical with that of the water table, is

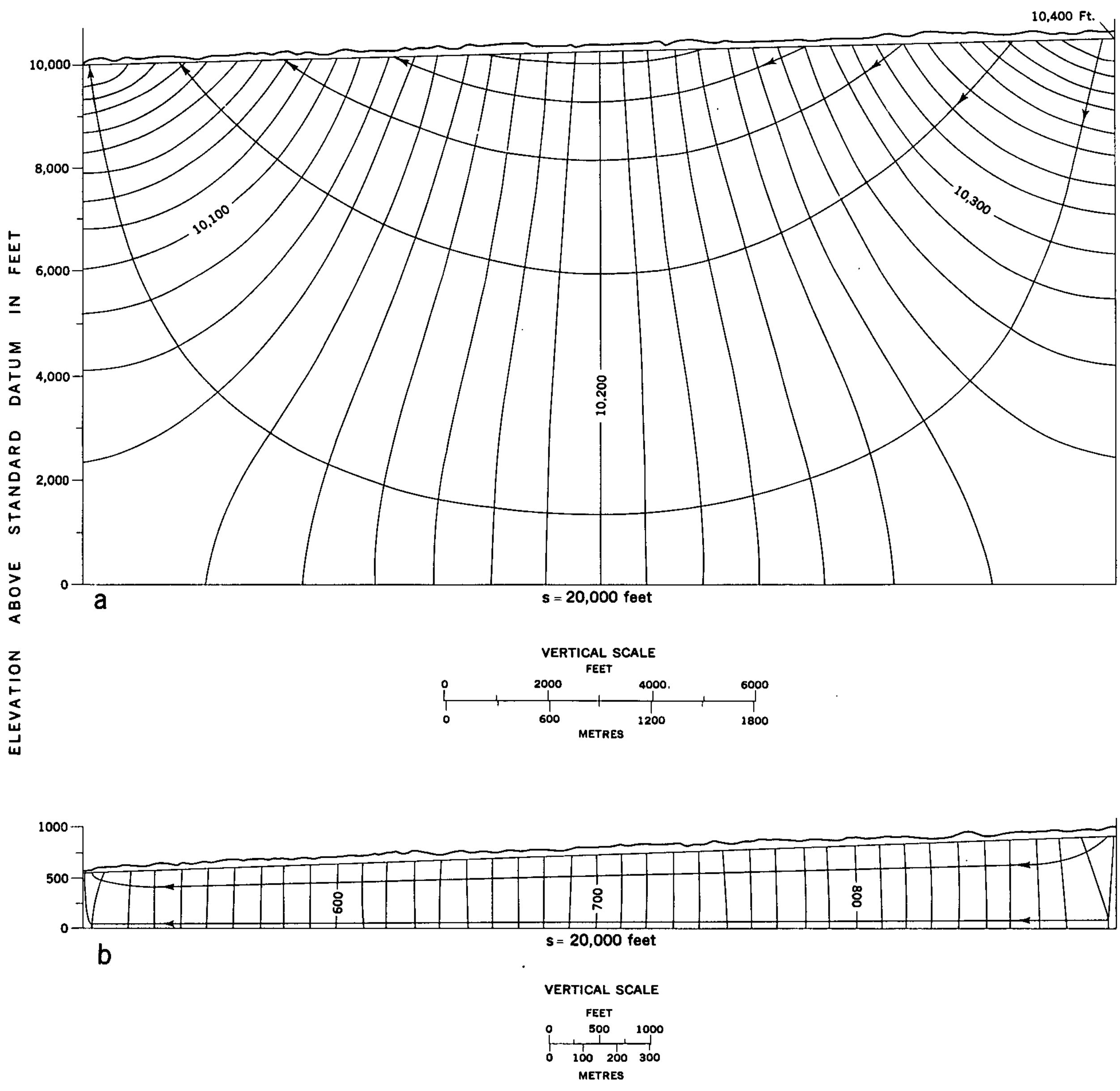



*Figure 25. Two-dimensional theoretical potential distributions and flow patterns (after Tóth, 1962).*

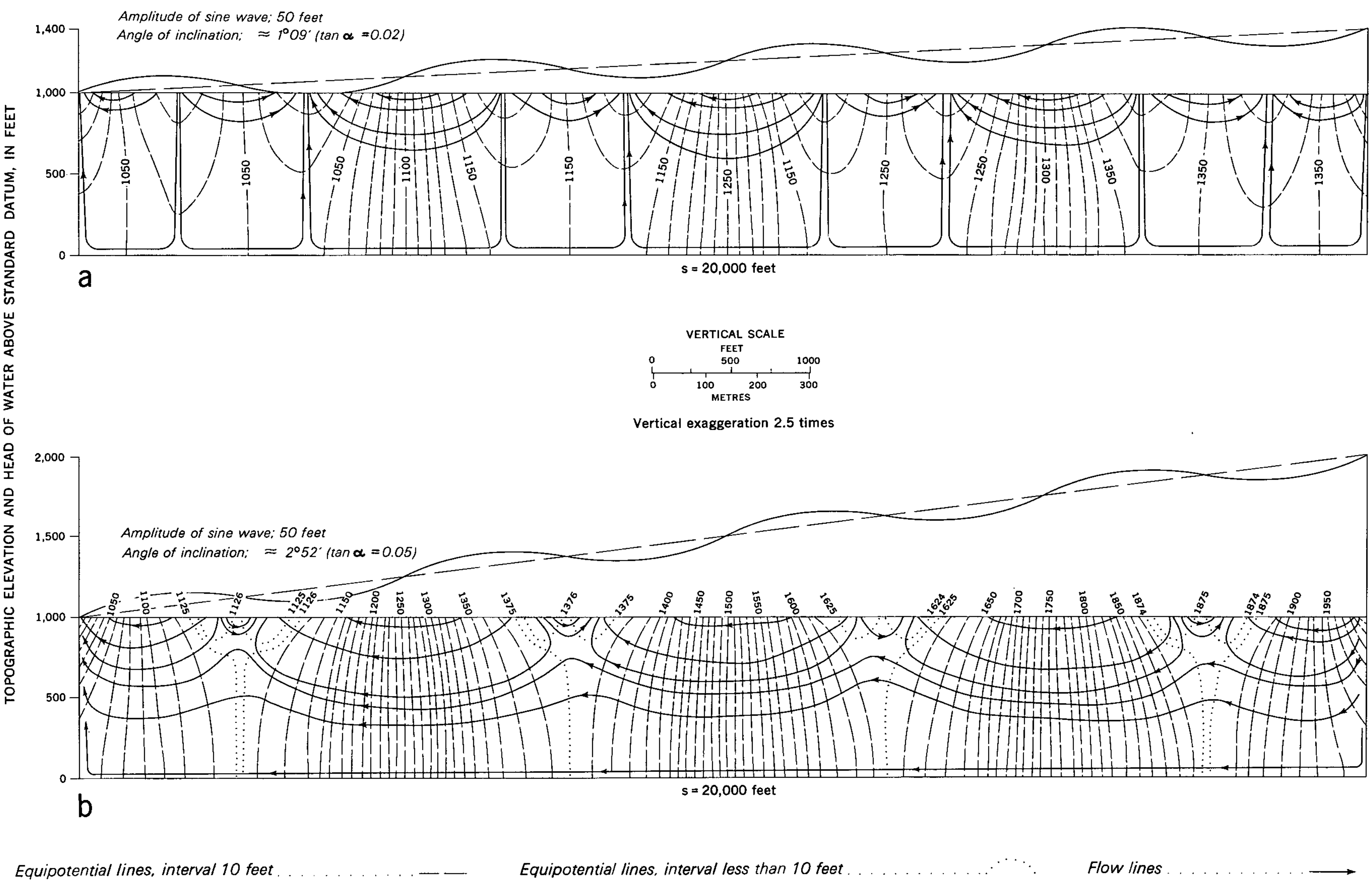



*Figure 26. Two-dimensional theoretical potential distributions and flow patterns (after Tóth, 1963).*

along a horizontal surface and this restricts the validity of the numerical results to small slopes of about 3° or less" (Tóth, 1963). The flow pattern is affected by the amplitude of the sine curve and the depth to the impermeable boundary. These flow patterns are developed for a uniformly permeable medium, and geological inhomogeneities will, of course, play an important role in modifying the theoretical patterns.

The Gravelbourg area is more or less a composite of Figure 26b (representing the southern upland) and Figure 25b (representing the Gravelbourg plain), although the depth to the impermeable layer is less in both cases. The Gravelbourg aquifer introduces a major geological inhomogeneity, which acts as a highway for the flow paths.

This theoretical treatment has been introduced here because it offers an insight into the type of flow pattern to be expected in the Gravelbourg area.

## GRAVELBOURG FLOW PATTERN

As the piezometric, hydrogeochemical, and surficial evidence have been discussed, together with a short introduction to the theoretical approach, it is now possible to prepare a flow pattern for the Gravelbourg area showing the relation of the aquifer to its hydrogeological environment. The flow pattern shown on Figure 2 is three-dimensional in nature and it was not possible to choose a section parallel to the horizontal component of flow throughout its length. The potential field shown on Figure

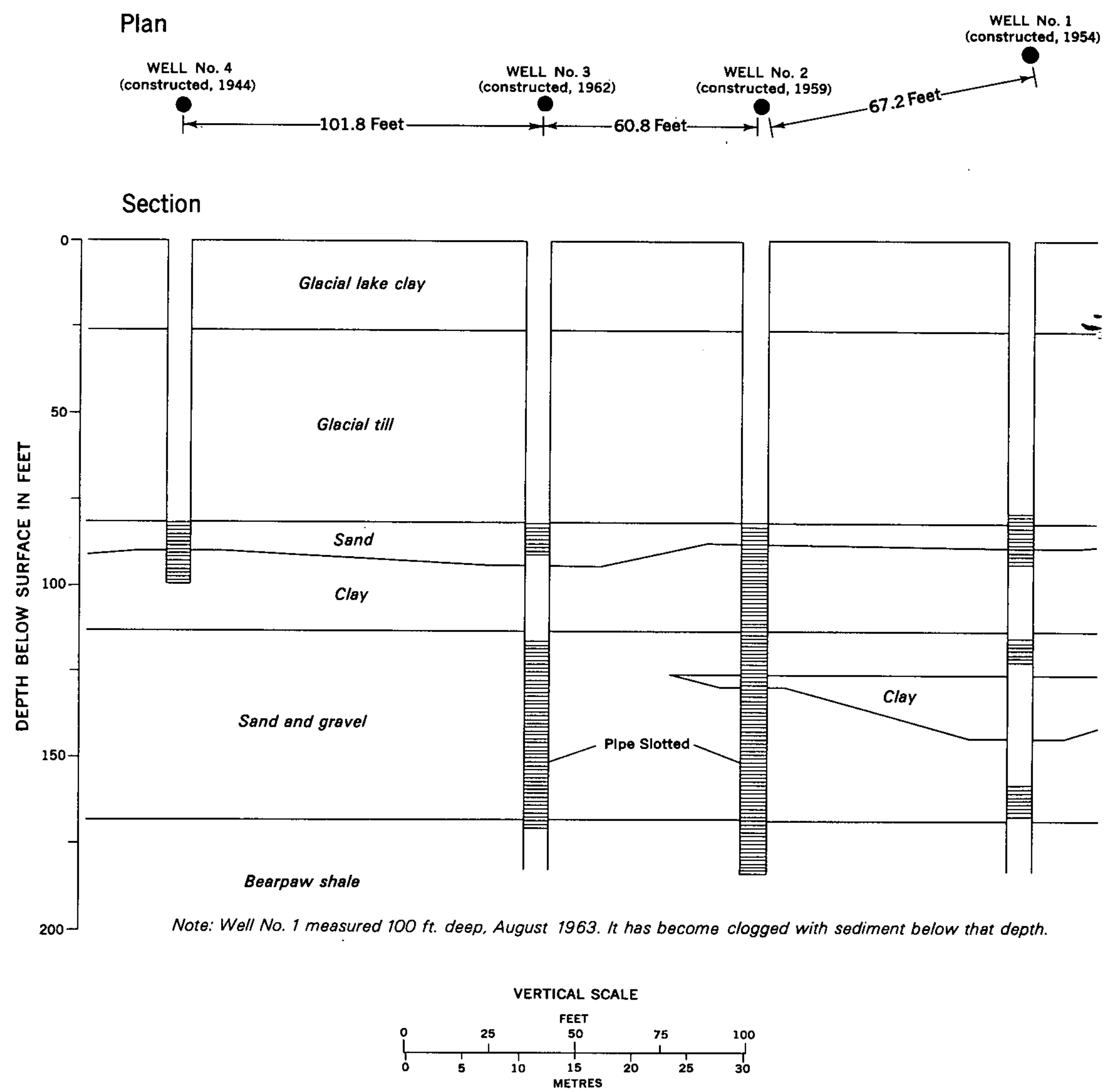



*Figure 27. Site of Gravelbourg pump test, August 10, 1963.*

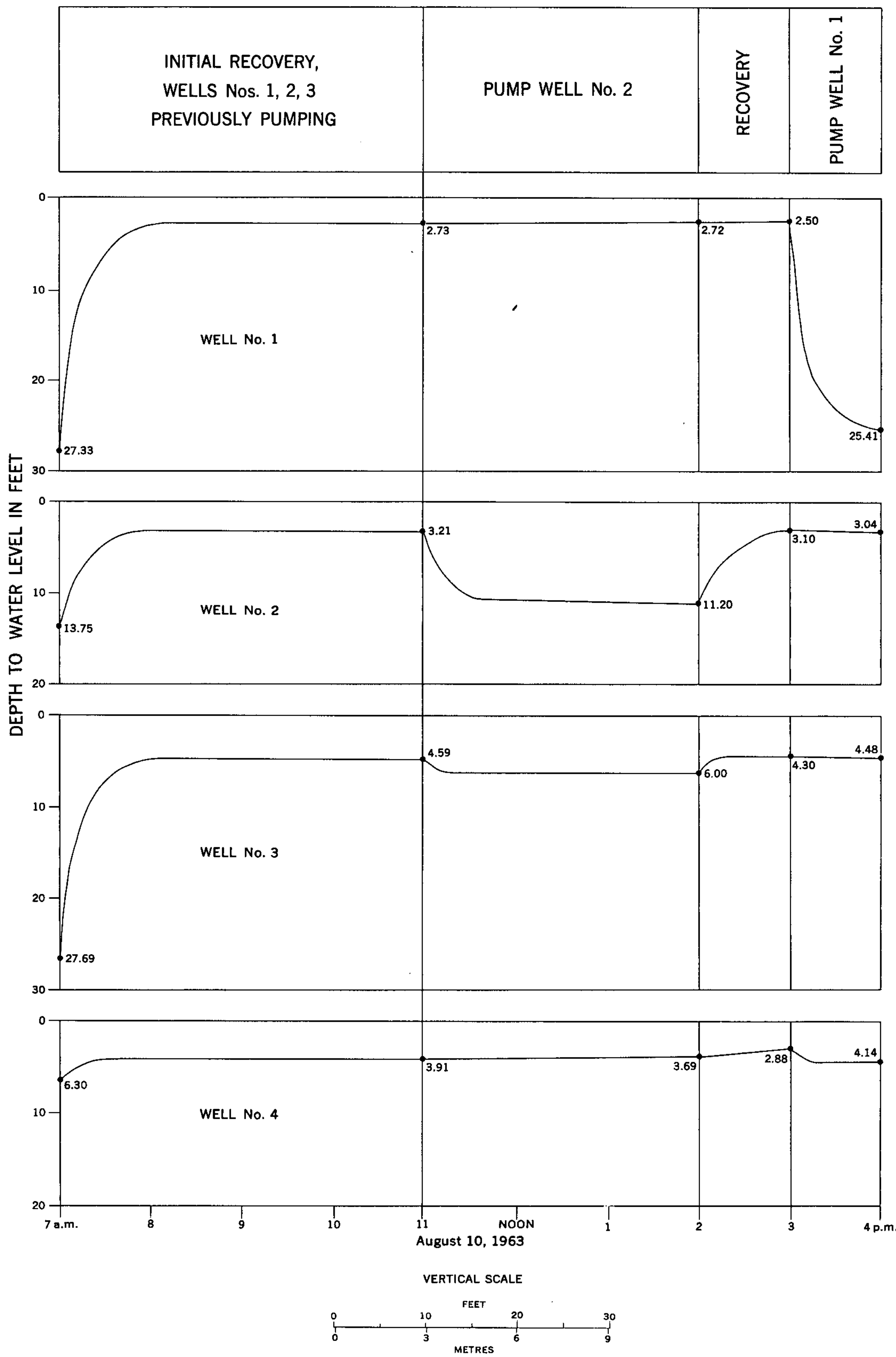



*Figure 28. Reaction of water levels to pump test procedure.*

2 is quantitatively correct, but as all the required flow lines could not be shown on any reasonable scale, arrows showing the qualitative direction of flow were used.

The Gravelbourg flow pattern is strikingly similar to that of the Darmody artesian basin (Meyboom, 1962), and also offers further field substantiation of the nature of groundwater flow postulated by Meyboom (1962) for the 'prairie profile.'

All evidence points to horizontal discharge from the aquifer through the silty clay phase of the lower stratified drift to the northeast. This further suggests the ultimate discharge of the water into Old Wives Lake and the associated large saline flat to the west and northwest of the lake.

The clustering of the equipotential contours along the eastern edge of the lower stratified drift (Figs. 2 and 14) is possibly indicative of a buried valley continuation of the Gravelbourg aquifer, which would provide a more permeable path toward Old Wives Lake. No evidence of such a deposit was found in drill-holes D and E, however.

## QUANTITATIVE HYDROLOGIC PROPERTIES OF THE AQUIFER

A pump test was carried out on the Gravelbourg town well field on August 10, 1963. The wells are located at the southwestern corner of the town on NW-36-10-5-W3. Figure 27 shows the location and depths of the four wells used and the nature of their aquifer penetration, based on records supplied by the town of Gravelbourg. The geologic information is taken from the logs submitted by the driller at the time each well was constructed. The upper sand at the base of the glacial till is obviously a very local deposit because it was not encountered at the piezometer site less than half a mile away. There, the top of the aquifer occurred at a depth of 104 feet, which is about the same elevation as the top of the lower sand and gravel in Figure 27. It should be noted that well 1 has become plugged and presently taps only the upper sand.

The pump test was performed between the hours of 7 a.m. and 4 p.m. The steps that were carried out and the general reaction of the water levels in the four wells to each drawdown and recovery were: (*See* Fig. 28)

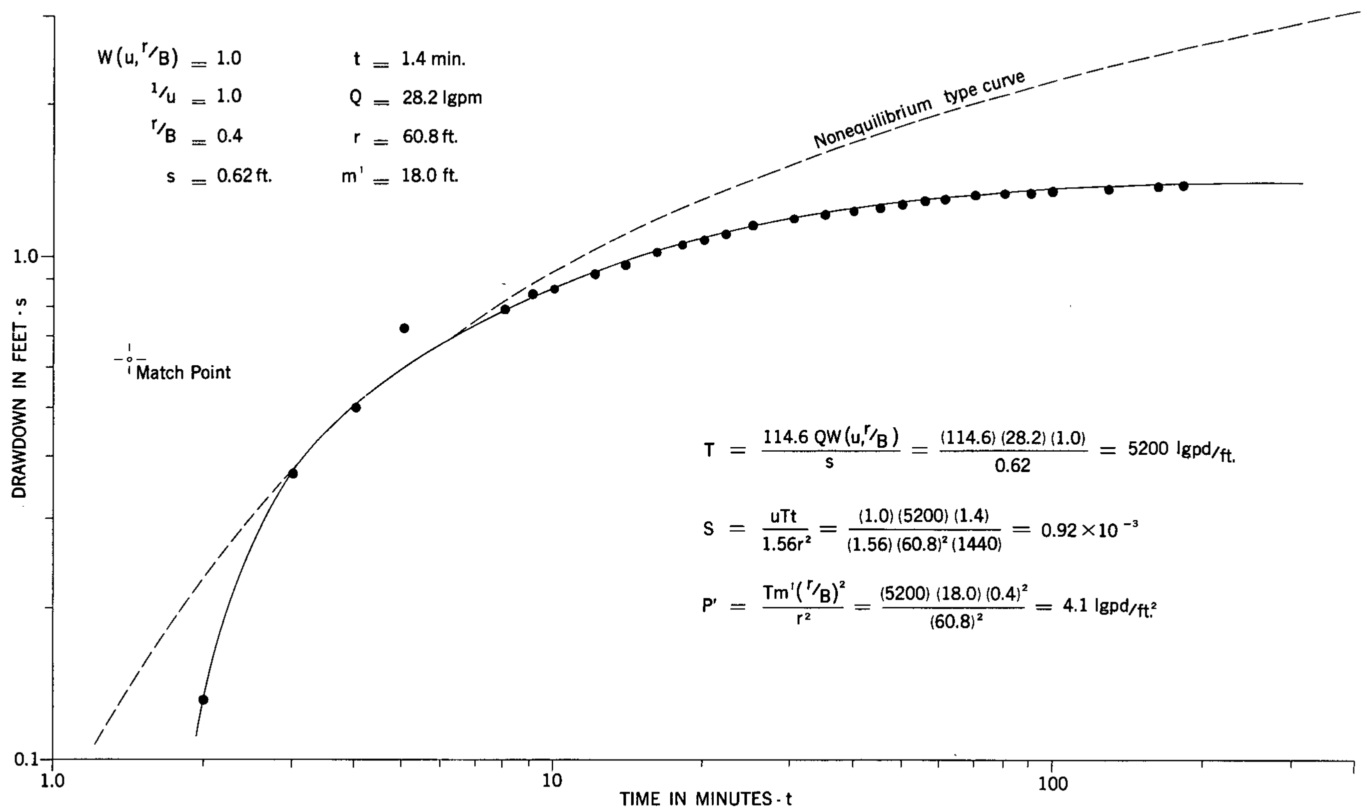



*Figure 29. Time-drawdown curve, well number 3, Gravelbourg pump test.*

1. 7 a.m. - 11 a.m.—All four wells were allowed to recover. Wells 1, 2, and 3 had previously been pumping to supply the town water system. By 11 a.m. the water levels in 1, 2, and 3 had essentially stabilized, but 4 was still recovering at an extremely low rate.

2. 11 a.m. - 2 p.m.—Well 2 was pumped at 28.2 Imperial gallons per minute with wells 1, 3, and 4 measured as observation wells. Only 3 showed a significant drawdown in response to the pumpage; 1 and 4 continued to recover but at a reduced rate.

3. 2 p.m. - 3 p.m.—The wells were again allowed to recover.

4. 3 p.m. - 4 p.m.—Well 1 was pumped at 15.0 Imperial gallons per minute with wells 2, 3, and 4 measured as observation wells. Only 4 showed a response to the pumpage; 2 and 3 continued to recover slowly.

The purpose of this discussion is to show the interconnection between wells 1 and 4 and between wells 2 and 3, and the apparent isolation of the two pair of wells. As well 1 is known to be plugged below the upper sand, the only

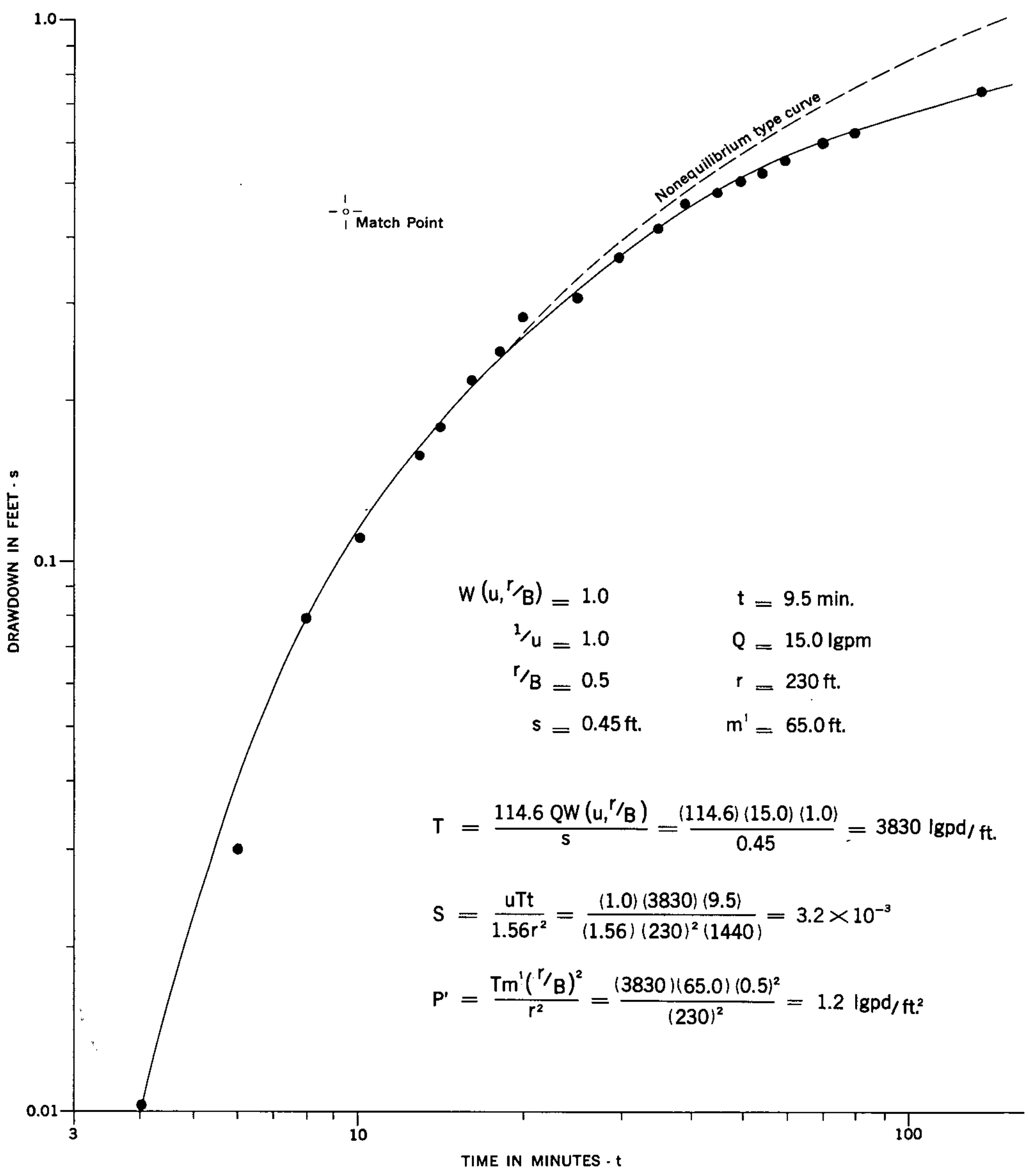



*Figure 30. Time-drawdown curve, well number 4, Gravelbourg pump test.*

logical interpretation is that wells 1 and 4 tap the upper sand while wells 2 and 3 tap the lower sand. Since wells 2 and 3 are reported to be slotted in the upper as well as the lower sand it is evident that they have become plugged in their upper parts.

The time-drawdown curve for well 3 during the pumping of well 2 (between 11 a.m. and 2 p.m., see Fig. 28) has been plotted on log-log paper and matched with the non-steady leaky artesian type curve (Walton, 1960). This curve, the match point chosen, and the calculation of the transmissibility and storage coefficients are shown on Figure 29. The calculations refer to the lower sand member which constitutes the actual Gravelbourg aquifer. The transmissibility is 5200 Imperial gallons/day/foot and the coefficient of storage $0.92 \times 10^{-3}$. For an aquifer thickness of 50 feet, this indicates a horizontal permeability of 104 Imperial gallons/day/square foot.

Leakage occurs from the upper sand through the confining clay into the aquifer when pumping takes place. Taking the thickness of this confining bed as 18 feet (Fig. 27), the vertical permeability of the clay is found to be 4.1 Imperial gallons/day/square foot.

Similarly the transmissibility and storage of the upper sand have been calculated from the superposition upon the leaky artesian type curves of the log-log time-drawndown curve for well 4 during the pumping of well 1 (between 3 p.m. and 4 p.m. - see Fig. 28). Since well 4 had never fully stabilized, the drawdowns were corrected for the extrapolated effect of the initial recovery. Figure 30 shows the curve and the calculations; the transmissibility is 3,830 Imperial gallons/day/foot (horizontal permeability = 383 Imperial gallons/day/square foot) and the coefficient of storage $3.2 \times 10^{-3}$. The transmissibility and storage refer to the local upper sand member and are of no further regional importance. The confining bed is glacial till; its saturated thickness is taken to be 65 feet and its vertical permeability is found to be 1.2 Imperial gallons/day/square foot.

It should be noted that the calculations for the upper sand may be in error, because the assumption in the development of the leaky artesian formula, which states that the aquifer must be situated between an impermeable bed and a leaky confining bed (Hantush and Jacob, 1955), is violated. In the upper sand, leakage is probably derived from both the overlying till and the underlying silty clay. This is especially critical in the calculation of the vertical permeability, which depends directly on the thickness of the confining bed through which leakage occurs. As stated, the confining bed is taken to be the overlying glacial till.

Owing to the effect of the leakage, the Jacob modified equilibrium method and Theis recovery method were not applicable.

The relation:

$$T=Kb$$

where

$T$ = transmissibility (gallons/day/foot)
$K$ = permeability (gallons/day/foot$^2$)
$b$ = thickness of the aquifer (feet)

gives an indication of the values of the transmissibility for the remainder of the Gravelbourg aquifer. From geological considerations we know that the aquifer is a phase of the lower stratified drift unit and that it grades into a silty clay to the north and to the west of Gravelbourg. It also thins in these directions. Thus both permeability and thickness decrease towards the outer limits of the aquifer, and consequently the transmissibility is highest in the Gravelbourg area and decreases rapidly towards the boundary of the aquifer.

The value of $T$ = 5,200 Igpd/ft, as determined from the pump test results, should therefore be considered as a maximum value for the Gravelbourg aquifer.

# *Groundwater Resources*

## QUANTITY

The safe yield of a groundwater basin is the amount of water that can be withdrawn from it annually without producing an undesired result (Todd, 1959). To avoid depleting the groundwater resources, the safe yield should not exceed the long-time mean annual water supply to the basin. In a 'confined' aquifer, such as the Gravelbourg aquifer, the water supply is limited by the rate at which water moves through the aquifer.

Assuming horizontal flow, the discharge is given by

$$Q = TIL \text{ (Ferris, 1962)}$$

where

Q = discharge through the aquifer in gallons/day
T = transmissibility in gallons/day/foot
I = hydraulic gradient in feet/mile
L = width, in miles, of the cross-section through which discharge occurs.

Considering the west to east flow towards Gravelbourg (Fig. 14) through the lens-shaped cross-section of aquifer and assuming average values of T = 4,000 Imperial gallons/day/foot, I = 5 feet/mile, and L = 10 miles, the discharge Q = 200,000 Imperial gallons/day or 280 acre-feet/year. This, then, represents a measure of the safe yield.

Another method of estimating the available groundwater resources is to consider the regional water balance. In its simplest form

$$P = R + E$$

where

P = precipitation
R = runoff
E = evapotranspiration

The runoff R consists of two components: direct surface runoff, and underground runoff. In the case of integrated surface drainage and well-developed groundwater flow systems, the groundwater discharges into the streams and becomes the base-flow component. On the Gravelbourg plain, however, there is no integrated surface runoff so that the entire excess of precipitation over evapotranspiration goes to recharge the soil moisture and groundwater bodies.

Table I lists the mean annual precipitation (1951 - 60) for Gravelbourg as 14.59 inches. Table V lists the mean annual actual evapotranspiration AE (as calculated by the Thornthwaite method for the period 1951 - 60) to be 14.13 inches and the moisture surplus MS as 0.19 inch (as found in the 10-year month by month analysis). This moisture surplus represents the runoff R, which in the absence of surface runoff consists wholly of groundwater recharge (soil moisture demands are satisfied within the Thornthwaite analysis). A rough estimate of the area from which groundwater recharges the aquifer (considering Figs. 2, 14, 16, 17) results in a figure of 80 square miles. Recharge of 0.19 inch over this area represents 35 x $10^6$ cubic feet/year or 780 acre-feet/year. Some of this recharge returns via shortcut flow paths to surface discharge areas (Fig. 2), so the actual safe yield of the aquifer would be considerably less than this figure indicates.

Considering this fact, the two values of safe yield as determined by the two methods (Q = TIL, P = R + E) are in good agreement. Conservatively, the safe yield may be considered to be 280 acre-feet/year. Present consumptive use is of the order of 40,000 Imperial gallons/day or 56 acre-feet/year, nearly all by the town of Gravelbourg.

Both the maximum transmissibility (5,200 Imperial gallons/day/ foot) and the safe yield (280 acre-feet/year) of the Gravelbourg aquifer represent very modest figures in the whole spectrum of groundwater development, but relative to the environment of southwestern Saskatchewan, groundwater resources of this order of magnitude are of great significance.

## QUALITY

Water from the Gravelbourg aquifer is highly mineralized $Na_2SO_4$ water (Fig. 21) with total dissolved solids ranging from 2,500 to 5,500 ppm (Fig. 24). Complete chemical analyses are contained in Appendix II. "The suitability of groundwater of a given quality for a particular purpose depends on the criteria or standards of acceptable quality for that use" (Todd, 1959). It is therefore necessary to discuss the chemical quality of the water from the Gravelbourg aquifer in terms of its utilization for domestic and agricultural purposes.

**Table XII International Standards of Drinking Water, World Health Organization (1958); Chemical Quality**

| | | Permissible (ppm) | Excessive (ppm) | Limiting Concentrations (ppm) |
|---|---|---|---|---|
| A. Toxic Substances | | | | |
| Lead | Pb | | | 0.1 |
| Selenium | Se | | | 0.05 |
| Arsenic | As | | | 0.2 |
| Chromium | $Cr^6$ | | | 0.05 |
| Cyanide | CN | | | 0.01 |
| B. Special Substances: | | | | |
| Fluoride | $F^-$ | | | > 1.5 harmful<br>< 0.5 harmful |
| Nitrate | $NO_3^-$ | | | 100 may harm infants |
| C. Potability: | | | | |
| Total Solids | | 500 | 1500 | |
| Iron | Fe | 0.3 | 1.0 | |
| Manganese | Mn | 0.1 | 0.5 | |
| Copper | Cu | 1.0 | 1.5 | |
| Zinc | Zn | 5.0 | 15.0 | |
| Calcium | Ca | 75 | 200 | |
| Magnesium | Mg | 50 | 150 | |
| Sulphate | $SO_4$ | 200 | 400 | |
| Chloride | Cl | 200 | 600 | |
| $MgSO_4 + Na_2SO_4$ | | 500 | 1000 | |

The World Health Organization (1958) standards of chemical quality for drinking water are shown in Table XII. An excessive concentration of any of the elements in part (A) of the table renders the water toxic, while the limiting concentrations listed in parts (B) and (C) are less restrictive and can be disregarded or adapted to local situations in specific instances.

Although the concentrations of the toxic substances were not determined in this study, it is obvious that they are not critical, because the water has been used for drinking without apparent ill effect for many years. On the whole, however, the potability of the water is far from good. Comparison of the analyses in Appendix II with the standards of Table XII shows that water from the aquifer exceeds the limits set up for fluoride, total solids, iron, magnesium, sulphate, and combined magnesium sulphate plus sodium sulphate. The high iron content is often due to rusty pipes, but the natural aquifer water is also high in iron. The excessive sodium sulphate has a laxative effect on those not accustomed to the water.

Barnyard contamination may lead to high nitrate contents and excessive bacteria counts. It should be stressed that it is necessary to have bacteriological as well as chemical analyses performed on a water before it can be considered potable.

Hem (1959) has listed the upper limits of dissolved solids concentration for water that is to be consumed by livestock (Table XIII).

The suitability of water for irrigation depends on the degree of mineralization, the sodium content and the concentration of boron (Wilcox, 1955). The sodium content is commonly expressed either by the per cent sodium (% Na) or by the sodium absorption ratio (SAR) where

$$\% \text{ Na} = \frac{(\text{Na} + \text{K})\ 100}{\text{Ca} + \text{Mg} + \text{Na} + \text{K}}$$

and

$$\text{SAR} = \frac{\text{Na}}{(\text{Ca} + \text{Mg})/2}$$

and all ionic concentrations are expressed in equivalents per million (milliequivalents per litre). The % Na of the aquifer water ranges from 45 to 86 and the SAR from 7.64 to 21.08.

**Table XIII Upper Limits of Dissolved Solids Concentration in Water To Be Consumed by Livestock**

| Livestock | Concentration, ppm |
|---|---|
| Poultry | 2860 |
| Pigs | 4290 |
| Horses | 6435 |
| Cattle (dairy) | 7150 |
| Cattle (beef) | 10,000 |
| Adult sheep | 12,900 |

Using the Wilcox (1948) diagram for irrigation water classification based on electrical conductivity (a measure of dissolved solids) and % Na, the water from the Gravelbourg aquifer is found to be unsuitable for irrigation.

Boron is necessary in very small quantities for normal growth of all plants, but in larger concentrations it becomes toxic (Todd, 1959). Boron determinations were not included in the analyses carried out for this study.

The fact that water from the Gravelbourg aquifer is barely potable and entirely unsuitable for irrigation being established, how then can this aquifer have economic significance?

The answer lies in the advances being made in the application of desalination processes to brackish water. The barrier at present is purely economic. "A cost target estimated to be the maximum that could be borne, if demineralized water were to be widely used in the United States, was set by the Interior Department's office of Saline Water at the start of its intensive desalination program in 1952: 38¢/kgal. for municipal water, 12¢/kgal. for irrigation water" (Howe, 1962). Present costs average $1.00/kgal.

In the ion exchange processes and electrodialysis, two of the favoured desalting processes, cost is directly proportional to salinity, so that economic desalination of brackish water may soon find application.

Looking to the future, therefore, the groundwater resources of the Gravelbourg aquifer deserve delineation. Even at present, the fact that few aquifers in the region can deliver even the modest yield of the Gravelbourg aquifer renders it economically important, despite the shortcomings of the quality of the water.

# *Conclusions*

1. The mean annual precipitation at Gravelbourg is 14.59 inches. Using the Thornthwaite procedure on a monthly basis for the 10-year period 1951 - 60, the mean annual potential evapotranspiration is found to be 22.23 inches, the mean annual actual evapotranspiration 14.13 inches, and the mean annual moisture surplus 0.19 inch.

2. There is no integrated surface drainage from the Gravelbourg plain or the morainal uplands into the streams that traverse the area. For this reason, the entire annual moisture surplus is available for groundwater recharge.

3. The preglacial bedrock topography that underlies the Pleistocene succession of glacial deposits forms a broad valley opening to the northeast. The western slope is gradual, the eastern slope, steep. The bedrock topography thus controls the extent of the glacial sediments. The bedrock consists of relatively impermeable shale of the Cretaceous Bearpaw Formation, which acts as the basal 'impermeable boundary' to groundwater flow patterns developed in the glacial deposits.

4. The Pleistocene succession of sediments present on the Gravelbourg plain includes surficial glacial-lake clay, glacial till, and a stratified drift deposit consisting of lacustrine silty clay and sand. The stratified drift can be correlated with the "lower stratified drift" of Christiansen (1959) in the Swift Current area. It is a proglacial sediment laid down during the retreat of the icefront that deposited the Wymark till. The overlying till is Aikins till.

5. The Gravelbourg aquifer is formed by the sand phase of the lower stratified drift together with associated thin outwash or fluvial sands and gravels. It reaches its maximum thickness of 50 feet near the town of Gravelbourg and thins and phases into the silty clay to the west and northwest. It underlies an area of about 90 square miles at depths of 85 to 175 feet.

6. Groundwater flow through the aquifer at Gravelbourg is essentially horizontal, with leakage from the aquifer into the till taking place, and leakage from the aquifer into the shale possible. Local downward leakage into the aquifer may occur in the cone of depression caused by the town well field.

7. The direction of flow is from west to east across the main body of the aquifer and from south to north along the eastern edge. The average gradient is about 5 feet per mile. A flowing artesian area covering several square miles exists around Gravelbourg. There is a local piezometric low around the Gravelbourg town well field.

8. The upland areas as well as the western three quarters of the Gravelbourg plain act as recharge areas for the aquifer. Wiwa Creek Valley and the base of the southern upland are discharge areas. The ultimate discharge from the aquifer is assumed to be to the northeast through the silty clay phase of the lower stratified drift to Old Wives Lake.

9. The geochemistry of the groundwater shows a geologic dependence, but does not show a correlation with the flow pattern, owing to: (a) the development of local flow systems in hummocky topography; (b) the subsequent variation in the flow paths of water recharging the aquifer; (c) the variation in the nature of the glacial till; and (d) the highly variable salt contents developed in the near-surface soils because of the semi-arid climate.

10. Tritium dating and pump-test evidence suggest a vertical permeability for the glacial till in the order of 0.05 to 5.0 gal/day/ft$^2$.

11. The maximum transmissibility of the aquifer (at Gravelbourg) is 5,200 Imperial gallons per day per foot, the coefficient of storage is $0.92 \times 10^{-3}$, and the horizontal permeability 104 Imperial gallons per day per square foot. The thickness, permeability, and transmissibility of the aquifer diminish outward from Gravelbourg.

12. The safe yield of the aquifer is 280 acre-feet per year; present utilization is 56 acre-feet per year.

13. The water from the aquifer is $Na_2SO_4$ water, high in total dissolved solids (2,500-5,500 ppm). It is barely potable without treatment, unsuitable for irrigation, but suitable, with treatment, for livestock. The economic importance of the aquifer will be enhanced with the advent of economic desalinization processes for brackish water.

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# Geologic Logs of Drill-Holes

A drilling program was carried out in the summer of 1963, consisting of seven drill-holes put down for stratigraphic information and one piezometer installation. The drilling was done by rotary rig and as a result the fines were not recovered from sand and gravel horizons. Clay, till, and shale, however, generally come up as small chips in the drilling fluid and can be fully described.

The location of the holes is shown in Figure 6, a graphical presentation of the interpretation of the logs showing the various geologic units is given in Figure 7.

### Drill-hole A

Location: SW-29-10-5-W3

Surface elevation: 2328′

| | |
|---|---|
| 0 - 6 | *Clay,* yellowish brown to tan, no silt or sand, very soft, roots and organic matter present, calcareous. |
| 6 - 30 | *Till,* dark yellowish brown, sandy and silty clay, becoming darker and harder with depth, calcareous. |
| 30 - 80 | *Till,* dark brownish grey, sandy and silty clay with abundant pebbles. Pebbles angular to subangular quartz, feldspar; subangular to subrounded gypsum and shale; rusty partings and nodules present, calcareous. |
| 80 - 124 | *Clay,* medium bluish grey, silty, no sand, granular appearance. |
| 124 - 127 | *Sand and gravel,* fine to coarse sand with pebble gravel, pebbles angular to subrounded quartz, feldspar, slate, carbonates; over-all colour yellowish brown. |
| 127 - 128 | *Clay,* as above. |
| 128 - 129 | *Sand and gravel,* as above. |
| 129 - 137 | *Clay,* as above, with black streaks of organic (? ) material. |
| 137 - 137½ | *Sand and gravel,* as above. |
| 137½ - 138 | *Clay,* as above. |
| 138 - 138½ | *Sand and gravel,* as above. |
| 138½ - 141 | *Clay,* as above. |
| 141 - 150 | *Shale,* hard, dark grey, no silt or sand, non-calcareous. |

### Drill-hole B

Location: NW-11-11-6-W3

Surface elevation: 2331′

| | |
|---|---|
| 0 - 18 | *Clay,* yellowish brown to tan, no silt or sand, very soft, roots and organic matter in top few feet only, calcareous. |
| 18 - 37 | *Till,* yellowish brown, silty, sandy and pebbly clay, calcareous. |
| 37 - 50 | *Clay,* medium bluish grey, silty, granular appearance, calcareous. |
| 50 - 72 | *Clay,* as above, with the black streaks of organic (? ) material. |
| 72 - 74 | *Sand and gravel,* fine to coarse sand with angular pebbles up to ½″, pebbles of red and yellow sandstone, red and brown slate, quartz, feldspars. |
| 74 - 75 | *Clay,* as above. |
| 75 - 76 | *Sand and gravel,* as above. |
| 76 - 100 | *Shale,* hard, dark grey, no sand or silt, non-calcareous. |

**Drill-hole C**

Location: SE-28-11-5-W3

Surface elevation: 2302′

| | |
|---|---|
| 0 - 21 | *Clay,* yellowish brown, silty and sandy near surface, becoming purer after a few feet, soft, calcareous. |
| 21 - 40 | *Till,* yellowish brown, silty and sandy clay with abundant small angular pebbles of quartz, sandstone, feldspars, carbonates, shale; calcareous. |
| 40 - 89 | *Till,* as above becoming bluish grey. |
| 89 - 90 | *Sand and gravel,* (no sample). |
| 90 - 91 | *Clay or till* (no sample). |
| 91 - 92 | *Sand and gravel,* fine to coarse sand with angular pebbles of quartz, feldspars, sandstones, carbonates; over-all colour yellowish brown. |
| 92 - 144 | *Clay,* yellowish brown to tan, with grey streaks throughout, silty, no sand or pebbles, calcareous. |
| 144 - 181 | *Sand,* light grey, fine to medium, with small fraction coarse sand and pebbles, quartzose, many dark minerals, slightly calcareous, 'salt and pepper sand'. |
| 181 - 183 | *Shale* (no sample). |

**Drill-hole D**

Location: NW-30-12-4-W3

Surface elevation: 2236′

| | |
|---|---|
| 0 - 5 | *Clay* |
| 5 - 6 | *Gravel,* alluvium (no sample). |
| 6 - 10 | *Clay* |
| 10 - 20 | *Till,* yellowish brown, silty and sandy clay with abundant small angular pebbles, calcareous. |
| 20 - 82 | *Till,* dark bluish grey, otherwise as above. |
| 82 - 82½ | *Sand and gravel,* up to ¼″ pebble gravel, angular to subangular pebbles, dark minerals, and light-coloured quartz and carbonates predominant, 'salt and pepper sand'. |
| 82½ - 88 | *Clay or till* (no sample). |
| 88 - 89 | *Sand and gravel,* as above. |
| 89 - 113 | *Clay,* medium bluish grey, silty, granular appearance, no sand or pebbles, calcareous. |
| 113 - 115 | *Sand,* fine to medium, quartzose with many dark minerals, 'salt and pepper sand'. |
| 115 - 115½ | *Clay,* as above. |
| 115½ - 119 | *Sand and gravel,* as above. |
| 119 - 125 | *Shale,* hard, dark grey, no sand or silt, non-calcareous. |

**Drill-hole E**

Location: E1/2-9-13-4-W3

Surface elevation: 2236′

| | |
|---|---|
| 0 - 21 | *Clay,* yellowish brown, silty, organic material in top few feet, small nodules of gypsum crystals, some rusty staining, calcareous. |
| 21 - 24 | *Sand and gravel,* fine to coarse sand, with small subangular to subrounded pebbles of quartz, sandstone, dark minerals, gypsum, over-all colour is yellowish brown. |
| 24 - 26 | *Clay,* as above, thinly interbedded with *sand,* as above. |
| 26 - 40 | *Till,* slightly silty and sandy clay, abundant pebbles, yellowish brown, calcareous. |
| 40 - 97 | *Till,* as above, becoming more silty and sandy, dark bluish grey. |

97 - 102 *Clay*, dark bluish grey, silty, no sand or pebbles, granular appearance, very calcareous, black streaks throughout.

102 - 103 *Sand and gravel*, subrounded to subangular pebbles of quartz, feldspars, carbonates, dark minerals, in 'salt and pepper sand'.

103 - 134 *Clay*, as above.

134 - 135 *Sand*, as above but no pebbles, fine to coarse.

135 - 180 *Clay* or *shale*, silty and very sandy, dark grey, no pebbles, very slightly calcareous, hard to drill.

180 - 220 Poor samples, *clay* or *shale* as above, with abundant hard chips of *shale* coming up; *shale*, hard, dark grey, no silt or sand, non-calcareous.

**Drill-hole F**

Location: S 1/2-14-12-4-W3

Surface elevation: 2278′

0 - 18 *Clay*, yellowish brown, no silt or sand, calcareous, contains gypsym crystals.

18 - 40 *Till*, silty and sandy clay, with angular pebbles of quartz, feldspar, carbonates, dark yellowish brown, calcareous; several *sand and gravel* horizons between 30 and 40 feet.

40 - 60 *Till*, as above, but bluish grey; *sand and gravel* layers at 55′, 58′, and 59′.

60 - 78 *Till*, as above, but light yellowish brown, fewer sand horizons.

78 - 112 *Clay*, silty and fine sandy, light grey, few pebbles, granular appearance, very calcareous.

112 - 115 *Sand and gravel*, fine to coarse sand with pebbles up to ¼″, angular, sandstone, slate, ironstone, quartz, dark rusty brown over-all colour.

115 - 125 *Shale*, hard, dark grey, no silt or sand, non-calcareous.

**Drill-hole G**

Location: NW-9-12-6-W3

Surface elevation: 2315′

0 - 11 *Clay*, light yellowish brown, silty, calcareous, soft.

11 - 24 *Sand*, fine, no pebbles, light grey, quartzose, slightly calcareous.

24 - 30 *Clay*, yellowish brown, silty, with streaks and irregular nodules of dark grey clay.

30 - 60 *Clay*, light brownish grey, lacks granular appearance, very little silt, very calcareous.

60 - 80 *Clay*, as above, becoming slightly silty and sandy.

80 - 131 *Clay*, as above, even less silty.

131 - 142 *Till*, silty and sandy clay with subangular pebbles of quartz, feldspars, carbonates, gypsum; medium bluish grey, 3-inch *gravel* lens at 136′.

142 - 150 *Shale*, hard, dark grey, no silt or sand, non-calcareous.

**Piezometer Installation**

Location: SW-1-11-5-W3

Surface elevation: 2293′

0 - 28 *Clay*, yellowish brown, no silt or sand, no organic material below soil zone (4′), a few small rusty inclusions, calcareous.

28 - 36 *Till*, silty and sandy clay, dark brown; many pebbles, angular to subangular, equidimensional, predominantly quartz, feldspar, carbonate, some gypsum, soft shale.

| | |
|---|---|
| 36 - 104 | *Till,* as above, but dark bluish grey. |
| 104 - 105 | *Sand,* yellowish brown, fine to medium, quartzose. |
| 105 - 105½ | *Clay,* yellowish brown, varved (?), no silt or sand, very hard. |
| 105½ - 106 | *Sand,* as above. |
| 106 - 110 | *Clay,* no sample. |
| 110 - 114 | *Sand and gravel,* as above, but with coarse gravel. |
| 114 - 114½ | *Clay,* no sample. |
| 114½ - 119 | *Sand,* as above. |
| 119 - 119½ | *Clay,* no sample. |
| 119½ - 120 | *Sand,* as above. |
| 120 - 121 | *Clay,* no sample. |
| 121 - 121½ | *Sand,* as above. |
| 121½ - 125 | *Clay,* no sample. |
| 125 - 147½ | *Sand,* dark grey, fine to medium, no gravel, quartzose, large percentage dark minerals, 'salt and pepper sand'. |
| 147½ - 148 | *Clay,* no sample. |
| 148 - 159 | *Sand,* as above. |
| 159 - 300 | *Shale,* very hard, dark grey to black, no sand or silt, some gypsum crystals, non-calcareous. |

Note: Chips of clay similar to that from 105 - 105 ½′ came up between 105 - 125′ and it can be assumed that the inter-sand layers of clay in this interval are composed of this material.

# Chemical Analyses

The chemical analyses reported in Table XIV were carried out at three different times. Samples listed as collected in 1936 are taken from Geological Survey of Canada Water Supply Papers 115 and 127, and the analyses were performed by the Industrial Waters Section of the Mines Branch of the then Department of Mines and Technical Surveys in that year. The samples collected in August 1962, were analyzed by the same agency during the winter of 1962 - 63. The samples collected in August 1963 were analyzed by the Provincial Laboratory of the Saskatchewan Department of Health in October 1963.

The location of wells from which water samples were collected is shown in Figure 18. All land locations are west of the third meridian.

The source of the water for each sample is considered to be the formation listed in the table. It is based on the available geological information together with consideration of the chemical analysis. The following code is used:

GLS – glacial lake sand
T – glacial till
SC – silty clay phase of the lower stratified drift
GA – Gravelbourg aquifer.

The term "total dissolved solids" (TDS) as used in this report refers to the "sum of constituents" as defined by Thomas (1953) as follows: "Sum of constituents is used to designate the total of all major ions as parts per million found in the water by analyses, including silica ($SiO_2$). The value of the bicarbonate ion found is converted to carbon to permit comparison with 'residue on evaporation.' 'Sum of constituents' is at times referred to as 'dissolved solids (calculated)'." It is apparent from the foregoing definition that 'dissolved solids (calculated)' is actually the correct term, but the author feels that the term 'total dissolved solids' is so firmly embedded in groundwater literature that its use will not create confusion.

Conductance is measured at 25°C and is reported in micromhos per centimetre. No exact relationship exists between conductance and dissolved solids in natural waters (Hem, 1959). However, in the relationship:

$$\underset{\text{(micromhos at 25°C)}}{\text{Conductance} \times A} = \underset{\text{(ppm)}}{\text{Dissolved solids}}$$

the value of A is generally found to be constant over fairly large areas for groundwater bodies. The relation for the Gravelbourg area is shown in Figure 31. Total dissolved solids values listed with an asterisk in Table XIV were derived from conductance measurements and the curve, rather than from a summation of the complete analysis.

In the initial analyses, ion concentrations were reported in parts per million by weight (ppm). The concentrations were then converted into equivalents per million (epm) by dividing each concentration by the equivalent weight of the ion in question. One epm can be defined, for a solution of specific gravity 1.00, as one equivalent weight in grams of the ion per one million grams of the solution (Todd, 1959). One epm is numerically equal to one milligram equivalent per litre (meq/1). The percentage equivalents per million were then calculated for use in the trilinear plots in the section on hydrogeology. The base exchange index (ieb) is defined in this same section; the % Na and the sodium absorption ratio (SAR) are discussed in the section on groundwater resources.

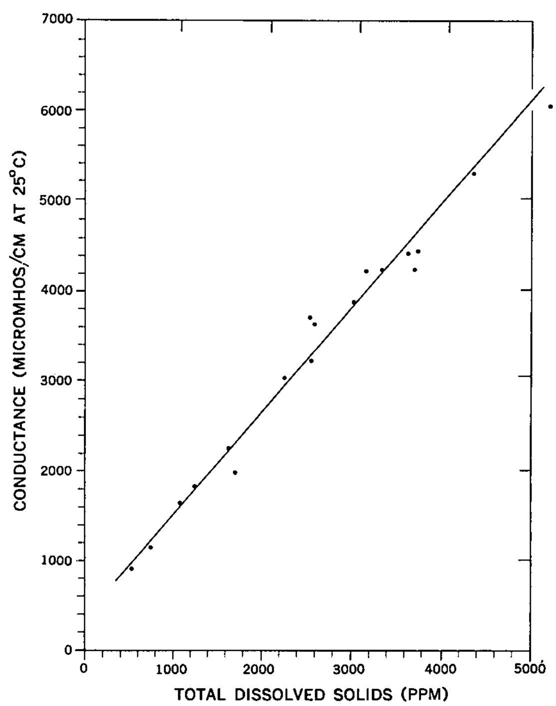


*Figure 31. Conductance vs. total dissolved solids, Gravelbourg area.*

Table XIV Chemical analyses of water samples, Gravelbourg area, Saskatchewan

| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample Properties | Sample No. | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| | Location | | NE-7-10-6 | SW-10-10-4 | NW-18-10-6 | NE-21-10-6 | SW-25-10-6 | SE-27-10-5 | NW-32-10-6 | NE-36-10-5 | SW-4-11-6 | NW-2-11-6 |
| | Date collected | | 1936 | 1936 | 1936 | August 1963 | August 1963 | August 1962 | August 1963 | August 1962 | August 1963 | August 1963 |
| | Depth (feet) | | 66 | 40 | 75 | 60 | 30 | 125 | 32 | 176 | 100 | 25 |
| | Formation† | | T | T | T | T | T | GA | T | GA | T | SC |
| General Chemical Properties | Conductance (micromhos/cm) | | – | – | – | 790 | 400 | 4475 | 1450 | 4225 | 3000 | 2000 |
| | TDS (ppm) | | 6420 | 800 | 5260 | 390* | 200* | 3743 | 970* | 3177 | 2310* | 1450* |
| | Hardness ($ppm CaCO_3$) | | 3000 | 700 | 2300 | 487 | 359 | 1322 | 910 | 595 | 1309 | 1683 |
| | Alkalinity ($ppm CaCO_3$) | | 110 | 555 | 415 | 535 | 216 | 566 | 443 | 595 | 1157 | 310 |
| | pH | | – | – | – | 7.0 | 7.6 | 7.7 | 7.2 | 7.8 | 7.6 | 7.5 |
| Crit-ical Irons | Fe – ppm | | – | – | – | – | – | – | – | – | – | – |
| | F – ppm | | – | – | – | – | – | 2.1 | – | 1.7 | – | – |
| | $NO_3$ – ppm | | – | – | – | 16.0 | 36.0 | 27. | 37.0 | 12. | 17. | 830. |
| Cations | Na | ppm | 1080. | 192. | 1020 | 24. | 18. | 715. | 238. | 840. | 1130. | 366. |
| | | epm | 47.0 | 8.4 | 44.5 | 1.0 | 0.8 | 31.1 | 10.4 | 36.6 | 49.2 | 15.9 |
| | | %epm | 52.0 | 58.0 | 56.0 | 8.9 | 10.0 | 54.0 | 36.2 | 75.2 | 65.2 | 31.9 |
| | K | ppm | – | – | – | 22. | 4.0 | 12.8 | 9.0 | 8.8 | 10. | 17. |
| | | epm | – | – | – | 0.6 | 0.1 | 0.3 | 0.2 | 0.2 | 0.3 | 0.4 |
| | | %epm | – | – | – | 5.3 | 1.2 | 0.4 | 0.8 | 0.3 | 0.4 | 0.8 |
| | Ca | ppm | 207. | 7.0 | 172. | 112. | 79. | 211. | 185. | 104. | 151. | 437. |
| | | epm | 10.3 | 0.3 | 8.6 | 5.6 | 3.9 | 10.5 | 9.2 | 5.2 | 7.5 | 21.8 |
| | | %epm | 11.0 | 2.0 | 11.0 | 49.5 | 48.5 | 18.2 | 32.0 | 10.6 | 9.9 | 43.7 |
| | Mg | ppm | 404. | 71.0 | 322. | 50. | 39. | 193. | 109. | 81.2 | 226. | 144. |
| | | epm | 33.2 | 5.8 | 26.4 | 4.1 | 3.2 | 15.9 | 8.9 | 6.7 | 18.5 | 11.8 |
| | | %epm | 37.0 | 40.0 | 33.0 | 36.3 | 40.3 | 27.5 | 31.0 | 13.7 | 24.5 | 23.6 |
| Anions | $HCO_3$ | ppm | 132. | 666. | 498. | 653. | 264. | 690. | 540. | 725. | 1412. | 378. |
| | | epm | 2.2 | 11.1 | 8.3 | 10.7 | 4.3 | 11.3 | 8.8 | 11.9 | 23.2 | 6.2 |
| | | %epm | 3.0 | 76.0 | 10.0 | 81.7 | 44.3 | 19.4 | 28.4 | 24.2 | 30.4 | 16.4 |
| | $SO_4$ | ppm | 4059. | 156.0 | 3192. | 85. | 250. | 2143. | 1000. | 1669. | 2400. | 1200. |
| | | epm | 84.5 | 3.3 | 66.5 | 1.8 | 5.2 | 44.6 | 20.9 | 34.7 | 50.0 | 25.0 |
| | | %epm | 93.0 | 22.0 | 83.0 | 13.7 | 53.5 | 76.8 | 67.9 | 70.6 | 65.5 | 66.0 |
| | Cl | ppm | 139. | 11.0 | 172. | 23. | 6.0 | 80.6 | 43. | 86.4 | 113. | 236. |
| | | epm | 4.9 | 0.3 | 4.8 | 0.6 | 0.2 | 2.3 | 1.2 | 2.4 | 3.2 | 6.7 |
| | | %epm | 4.0 | 2.0 | 7.0 | 4.6 | 2.2 | 3.9 | 3.9 | 5.0 | 4.1 | 17.6 |
| Ratios | Mg/Ca | | 3.36 | 20.0 | 3.00 | 0.73 | 0.82 | 1.51 | 0.97 | 1.29 | 2.47 | 0.54 |
| | Na/Ca + Mg | | 1.08 | 1.38 | 1.28 | 1.27 | 0.10 | 1.18 | 0.57 | 3.10 | 1.89 | 0.47 |
| | $SO_4/Cl$ | | 23.2 | 11.0 | 11.8 | 3.0 | 26.0 | 19.7 | 17.4 | 14.1 | 15.6 | 3.72 |
| | ieb | | -0.50 | -0.57 | -0.53 | -0.08 | -0.07 | -0.52 | -0.32 | -0.74 | -0.63 | -0.63 |
| | $SO_4/HCO_3$ | | 31.00 | 0.29 | 8.30 | 0.17 | 1.21 | 3.96 | 2.37 | 2.92 | 2.16 | 4.04 |
| | %Na | | 52 | 58 | 56 | 9 | 10 | 54 | 36 | 75 | 65 | 32 |
| | SAR | | 10.01 | 4.82 | 10.70 | 0.46 | 0.43 | 8.40 | 3.47 | 14.98 | 14.00 | 3.89 |

† T = Glacial till; GA = Gravelbourg aquifer; SC = silty clay phase of lower stratified drift; GLS = glacial lake sand.

Table XIV (cont'd)

| | | | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample Properties | Sample No. | | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| | Location | | NW-2-11-5 | NE-2-11-5 | SW-7-11-5 | SW-8-11-5 | SE-12-11-5 | NW-14-11-6 | SW-16-11-5 | SE-16-11-5 | SW-19-11-5 | NW-28-11-6 |
| | Date collected | | August 1962 | August 1962 | August 1962 | August 1962 | August 1962 | August 1963 | August 1962 | August 1962 | August 1962 | 1936 |
| | Depth (feet) | | 35 | 120 | 28 | 125 | 60 | 45 | 120 | 103 | 48 | 33 |
| | Formation † | | T | GA | T | GA | T | SC | GA | GA | T | T |
| General Chemical Properties | Conductance (micromhos/cm) | | 4430 | 3898 | 903 | 5307 | 3660 | 1400 | 4213 | 4257 | 1986 | – |
| | TDS (ppm) | | 3616 | 3056 | 541 | 4360 | 2605 | 920* | 3743 | 3334 | 1697 | 1460 |
| | Hardness (ppm $CaCO_3$) | | 1188 | 1110 | 434 | 1324 | 392 | 763 | 1200 | 1284 | 472 | 1400 |
| | Alkalinity (ppm $CaCO_3$) | | 556 | 539 | 444 | 565 | 789 | 543 | 600 | 639 | 502 | 350 |
| | pH | | 7.7 | 7.8 | 8.1 | 7.6 | 7.9 | 7.3 | 7.7 | 7.8 | 8.1 | – |
| Critical Ions | Fe – ppm | | 6.2 | 6.7 | 0.14 | 6.3 | 3.6 | – | 2.3 | 17.7 | 0.7 | – |
| | F – ppm | | 2.1 | 1.7 | 0.5 | 3.7 | 1.7 | – | 4.3 | 2.0 | 1.3 | – |
| | $NO_3$ – ppm | | 9.6 | 14.0 | 16.0 | 9.7 | 2.4 | 2.0 | 73.0 | 8.1 | 0.0 | – |
| Cations | Na | ppm | 725. | 585. | 34.5 | 935. | 785. | 318. | 677. | 630. | 305. | 188. |
| | | epm | 31.6 | 25.4 | 1.5 | 40.6 | 34.2 | 13.8 | 29.4 | 27.4 | 13.5 | 8.2 |
| | | %epm | 56.9 | 53.0 | 14.4 | 60.2 | 81.0 | 45.8 | 54.7 | 51.6 | 58.5 | 36.0 |
| | K | ppm | 12.5 | 10.9 | 16.5 | 13.0 | 5.9 | 8.0 | 8.2 | 8.3 | 8.6 | – |
| | | epm | 0.3 | 0.3 | 0.4 | 0.3 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | – |
| | | %epm | 0.5 | 0.6 | 3.7 | 0.4 | 0.4 | 0.7 | 0.4 | 0.4 | 0.9 | – |
| | Ca | ppm | 189. | 198. | 67.5 | 220. | 75.0 | 161. | 155. | 179. | 78.6 | 121. |
| | | epm | 9.4 | 9.8 | 3.4 | 11.0 | 3.74 | 8.1 | 7.7 | 8.9 | 3.9 | 6.0 |
| | | %epm | 16.9 | 20.6 | 31.8 | 16.3 | 8.9 | 26.9 | 14.4 | 16.8 | 16.9 | 26.0 |
| | Mg | ppm | 174. | 150. | 64.5 | 188 | 49.7 | 97. | 198. | 203. | 67.0 | 108. |
| | | epm | 14.3 | 12.3 | 5.3 | 15.5 | 4.1 | 8.0 | 16.3 | 16.7 | 5.5 | 8.8 |
| | | %epm | 25.7 | 25.7 | 50.0 | 22.9 | 9.7 | 26.6 | 30.2 | 31.4 | 23.8 | 38.0 |
| Anions | $HCO_3$ | ppm | 678. | 657. | 542. | 688. | 960. | 662. | 732. | 779. | 612. | 422. |
| | | epm | 11.1 | 10.8 | 8.9 | 11.3 | 15.7 | 10.9 | 12.0 | 12.8 | 10.0 | 7.0 |
| | | %epm | 19.7 | 22.5 | 87.5 | 16.7 | 38.2 | 33.4 | 23.0 | 23.9 | 43.6 | 30.0 |
| | $SO_4$ | ppm | 2065. | 1678. | 50.4 | 2569. | 1106. | 980. | 1782. | 1789. | 598. | 742. |
| | | epm | 43.0 | 34.9 | 1.1 | 53.5 | 23.0 | 20.4 | 37.2 | 37.2 | 12.5 | 15.4 |
| | | %epm | 76.1 | 73.0 | 10.3 | 80.5 | 55.8 | 62.5 | 71.4 | 69.9 | 54.4 | 66.0 |
| | Cl | ppm | 84.5 | 77.7 | 7.7 | 62.1 | 91.3 | 50. | 105. | 119. | 15.9 | 27. |
| | | epm | 2.4 | 2.2 | 0.2 | 1.8 | 2.6 | 1.4 | 3.0 | 3.4 | 0.4 | 0.8 |
| | | %epm | 4.2 | 4.6 | 2.1 | 2.6 | 6.3 | 4.1 | 5.7 | 6.3 | 1.8 | 4.0 |
| Ratios | Mg/Ca | | 1.52 | 1.25 | 1.57 | 1.40 | 1.03 | 0.99 | 2.10 | 1.87 | 1.41 | 1.46 |
| | Na/Ca + Mg | | 1.34 | 1.16 | 0.22 | 1.54 | 4.37 | 0.86 | 1.23 | 1.08 | 1.46 | 0.57 |
| | $SO_4$/Cl | | 18.2 | 15.9 | 4.9 | 31.0 | 8.80 | 14.6 | 12.5 | 11.1 | 30.2 | 16.5 |
| | ieb | | -0.56 | -0.51 | -0.16 | -0.60 | -0.80 | -0.40 | -0.52 | -0.49 | -0.59 | -0.33 |
| | $SO_4/HCO_3$ | | 3.87 | 3.25 | 0.12 | 4.82 | 1.46 | 1.87 | 3.10 | 2.92 | 1.25 | 2.20 |
| | %Na | | 57 | 53 | 14 | 60 | 81 | 46 | 55 | 51 | 58 | 36 |
| | SAR | | 9.16 | 7.64 | 0.72 | 11.15 | 17.47 | 4.90 | 8.51 | 7.64 | 6.11 | 3.03 |

**Table XIV (cont'd)**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample Properties | Sample No. | | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
| | Location | | NE-25-11-6 | NE-30-11-5 | SW-28-11-5 | SW-26-11-5 | NE-24-11-5 | NW-36-11-5 | SE-32-11-4 | SW-6-12-6 | NW-15-12-5 | NW-24-12-6 |
| | Date collected | | 1936 | August 1962 | August 1962 | August 1962 | August 1962 | August 1962 | August 1962 | 1936 | August 1963 | August 1963 |
| | Depth (feet) | | 44 | 130 | 135 | 22 | 120 | 130 | 70 | 15 | 20 | 38 |
| | Formation † | | T | T | GA | T | GA | GA | T | T | GLS | GLS |
| General Chemical Properties | Conductance (micromhos/cm) | | – | 1636 | 6044 | 2248 | 3709 | 2332 | 1805 | – | 400 | 560 |
| | TDS (ppm) | | 3300 | 1093 | 5207 | 1607 | 2576 | 2574 | 1243 | 560 | 200* | 250* |
| | Hardness (ppm $CaCO_3$) | | 1800 | 832 | 2250 | 651 | 280 | 618 | 500 | 375 | 305 | 438 |
| | Alkalinity (ppm $CaCO_3$) | | 470 | 313 | 521 | 463 | 776 | 551 | 429 | 310 | 344 | 392 |
| | pH | | – | 7.7 | 7.7 | 7.8 | 8.0 | 7.7 | 7.7 | – | 7.5 | 8.1 |
| Critical Ions | Fe – ppm | | – | 0.17 | 0.53 | 0.68 | 2.9 | 5.2 | – | – | – | – |
| | F – ppm | | – | 0.86 | 2.85 | 0.85 | 1.4 | 1.4 | – | – | – | – |
| | $NO_3$ – ppm | | – | 1.98 | 36 | 0.50 | 12.0 | 6.8 | 2.7 | – | 1.0 | 6.0 |
| Cations | Na | ppm | 570. | 28.5 | 842. | 300. | 810. | 642. | 235. | 123. | 19. | 41. |
| | | epm | 24.8 | 1.2 | 36.6 | 13.1 | 35.2 | 27.9 | 10.4 | 5.4 | 0.8 | 1.8 |
| | | %epm | 49.0 | 7.0 | 44.6 | 59.0 | 85.9 | 69.3 | 50.6 | 55.0 | 11.2 | 17.0 |
| | K | ppm | – | 9.0 | 17.5 | 4.7 | 5.9 | 10.9 | 8.7 | – | 7.0 | 5.0 |
| | | epm | – | 0.2 | 0.5 | 0.1 | 0.2 | 0.3 | 0.2 | – | 0.2 | 0.1 |
| | | %epm | – | 1.1 | 0.6 | 0.5 | 0.5 | 0.7 | 1.0 | – | 2.8 | 0.8 |
| | Ca | ppm | 208. | 177. | 411. | 90.3 | 50.8 | 113. | 86.6 | 43. | 67.0 | 96.0 |
| | | epm | 10.4 | 8.8 | 20.5 | 4.5 | 2.5 | 5.7 | 4.3 | 2.1 | 3.3 | 4.8 |
| | | %epm | 21.0 | 48.8 | 25.0 | 20.2 | 6.2 | 13.9 | 21.0 | 21.0 | 46.5 | 45.4 |
| | Mg | ppm | 184. | 94.9 | 297. | 103. | 37.2 | 81.7 | 68.6 | 28. | 34.0 | 48.0 |
| | | epm | 15.1 | 7.8 | 24.4 | 4.5 | 3.1 | 6.7 | 5.7 | 2.3 | 2.8 | 3.9 |
| | | %epm | 30.0 | 43.1 | 29.8 | 20.2 | 7.5 | 16.6 | 27.5 | 24.0 | 39.4 | 36.8 |
| Anions | $HCO_3$ | ppm | 764. | 381. | 635. | 565. | 946. | 672. | 523. | 372. | 420. | 478. |
| | | epm | 12.7 | 6.3 | 10.4 | 9.3 | 15.5 | 11.0 | 8.6 | 6.2 | 6.9 | 7.9 |
| | | %epm | 24.0 | 42.4 | 12.9 | 35.2 | 37.8 | 27.4 | 41.5 | 63.0 | 84.1 | 68.5 |
| | $SO_4$ | ppm | 1796. | 298. | 2995. | 784. | 1063. | 1265. | 519. | 152. | 60. | 140. |
| | | epm | 37.4 | 6.2 | 62.4 | 16.3 | 22.2 | 26.4 | 10.8 | 3.2 | 1.2 | 2.9 |
| | | %epm | 70.0 | 42.1 | 77.4 | 61.6 | 54.0 | 65.5 | 52.4 | 33.0 | 14.2 | 25.2 |
| | Cl | ppm | 131. | 80.8 | 276. | 28.2 | 120 | 103. | 45.2 | 15. | 4.0 | 24. |
| | | epm | 3.7 | 2.3 | 7.8 | 0.8 | 3.4 | 2.9 | 1.3 | 0.4 | 0.1 | 0.7 |
| | | %epm | 6.0 | 15.5 | 9.7 | 3.2 | 8.3 | 7.2 | 6.2 | 4.0 | 1.7 | 6.3 |
| Ratios | Mg/Ca | | 1.43 | 0.88 | 1.19 | 1.88 | 1.21 | 1.22 | 1.30 | 1.14 | 0.85 | 0.81 |
| | Na/Ca + Mg | | 0.96 | 0.09 | 0.82 | 1.01 | 6.31 | 2.30 | 1.06 | 1.22 | 0.13 | 0.21 |
| | $SO_4$/Cl | | 11.7 | 2.61 | 7.9 | 19.2 | 6.5 | 9.1 | 8.44 | 8.2 | 12.0 | 4.15 |
| | ieb | | -0.46 | -0.09 | -0.39 | -0.49 | -0.85 | -0.67 | -0.48 | -0.53 | -0.11 | -0.11 |
| | $SO_4/HCO_3$ | | 2.92 | 1.00 | 6.00 | 1.75 | 1.43 | 2.39 | 1.26 | 0.52 | 0.17 | 0.37 |
| | %Na | | 49 | 6.8 | 45 | 50 | 86 | 69 | 50 | 55 | 11 | 17 |
| | SAR | | 7.00 | 0.43 | 7.72 | 5.12 | 21.08 | 11.23 | 4.59 | 3.65 | 0.46 | 0.87 |

Table XIV (cont'd)

| | | | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 |
|---|---|---|---|---|---|---|---|---|---|---|
| Sample Properties | Sample No. | | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 |
| | Location | | SW-27-12-6 | SE-1-13-5 | SE-14-13-4 | SW-14-13-4 | E½-20-13-3 | NW-19-13-2 | NW-5-14-2 | S½-17-14-1 |
| | Date collected | | August 1962 | August 1962 | 1936 | 1936 | August 1963 | August 1963 | August 1963 | August 1963 |
| | Depth (feet) | | 72 | 100 | 80 | 137 | 115 | 15 | 89 | Old Wives Lake |
| | Formation † | | T | T | T | SC | SC | T | SC | – |
| General Chemical Properties | Conductance (micromhos/cm) | | 1117. | 3030. | – | – | 2100. | 1400 | 2000 | 4200 |
| | TDS (ppm) | | 756 | 2268 | 3060 | 4140 | 1530* | 920 | 1450 | 3350 |
| | Hardness ($ppm\ CaCO_3$) | | 575 | 970 | 1600 | 2800 | 1215 | 487 | 900 | 1274 |
| | Alkalinity ($ppm\ CaCO_3$ | | 320 | 663 | 950 | 955 | 767 | 424 | 679 | 1716 |
| | pH | | 8.0 | 7.9 | – | – | 7.3 | 7.9 | 7.9 | 9.2 |
| Critical Ions | Fe – ppm | | 0.0 | 0.0 | – | – | – | – | – | – |
| | F – ppm | | 0.42 | 1.1 | – | – | – | – | – | – |
| | $NO_3$ – ppm | | 0.9 | 52.0 | – | – | 14.0 | 255 | 13.0 | 80 |
| Cations | Na | ppm | 35.0 | 405. | 628. | 826. | 595. | 412. | 700 | 2800 |
| | | epm | 1.5 | 17.6 | 27.4 | 36.0 | 25.9 | 17.9 | 30.5 | 122. |
| | | %epm | 11.1 | 47.5 | 53.9 | 56.0 | 52.0 | 64.4 | 62.4 | 81.6 |
| | K | ppm | 6.2 | 6.2 | – | – | 7.0 | 9.0 | 8.0 | 9.0 |
| | | epm | 0.2 | 0.2 | – | – | 0.2 | 0.2 | 0.2 | 2.3 |
| | | %epm | 1.7 | 0.6 | – | – | 0.4 | 0.7 | 0.4 | 1.5 |
| | Ca | ppm | 136. | 179. | 222. | 64. | 224. | 106. | 161. | 55. |
| | | epm | 6.8 | 8.9 | 11.1 | 3.2 | 11.2 | 5.3 | 8.1 | 2.7 |
| | | %epm | 51.5 | 24.0 | 21.8 | 5.0 | 22.5 | 19.0 | 16.7 | 1.8 |
| | Mg | ppm | 57.4 | 127. | 150. | 305. | 159. | 54. | 121. | 276. |
| | | epm | 4.7 | 10.5 | 12.3 | 25.2 | 12.5 | 4.4 | 10.0 | 22.6 |
| | | %epm | 35.8 | 28.2 | 24.2 | 39.0 | 25.1 | 15.9 | 20.5 | 15.1 |
| Anions | $HCO_3$ | ppm | 390. | 809. | 1130. | 1135. | 936. | 517. | 828. | 1715. |
| | | epm | 6.4 | 13.2 | 18.6 | 18.7 | 15.4 | 7.9 | 13.6 | 28.2 |
| | | %epm | 48.6 | 36.4 | 36.5 | 29.0 | 29.2 | 28.2 | 28.0 | 19.6 |
| | $SO_4$ | ppm | 276. | 1019. | 1423. | 1886. | 1700. | 850. | 1600. | 5300. |
| | | epm | 5.8 | 21.2 | 29.7 | 39.3 | 35.4 | 17.7 | 33.4 | 110.0 |
| | | %epm | 43.6 | 58.4 | 58.4 | 61.2 | 67.0 | 63.2 | 69.0 | 76.1 |
| | Cl | ppm | 37.3 | 66.0 | 87. | 228. | 71. | 85. | 52. | 220. |
| | | epm | 1.1 | 1.9 | 2.5 | 6.4 | 2.0 | 2.4 | 1.5 | 6.2 |
| | | %epm | 8.0 | 5.1 | 5.1 | 9.8 | 3.8 | 8.6 | 3.0 | 4.3 |
| Ratios | Mg/Ca | | 0.70 | 1.18 | 1.10 | 7.90 | 1.11 | 0.83 | 1.23 | 8.40 |
| | Na/Ca + Mg | | 0.15 | 0.92 | 1.17 | 1.27 | 1.09 | 1.84 | 1.68 | 4.82 |
| | $SO_4$/Cl | | 5.45 | 11.4 | 11.9 | 6.13 | 17.7 | 7.4 | 22.3 | 17.8 |
| | ieb | | -0.05 | -0.45 | -0.52 | -0.51 | -0.47 | -0.61 | -0.62 | -0.85 |
| | $SO_4/HCO_3$ | | 0.90 | 1.60 | 1.60 | 2.10 | 2.30 | 2.24 | 2.46 | 3.90 |
| | %Na | | 12 | 47 | 54 | 56 | 52 | 64 | 62 | 82 |
| | SAR | | 0.64 | 5.66 | 8.05 | 9.67 | 7.55 | 8.17 | 10.15 | 34.40 |

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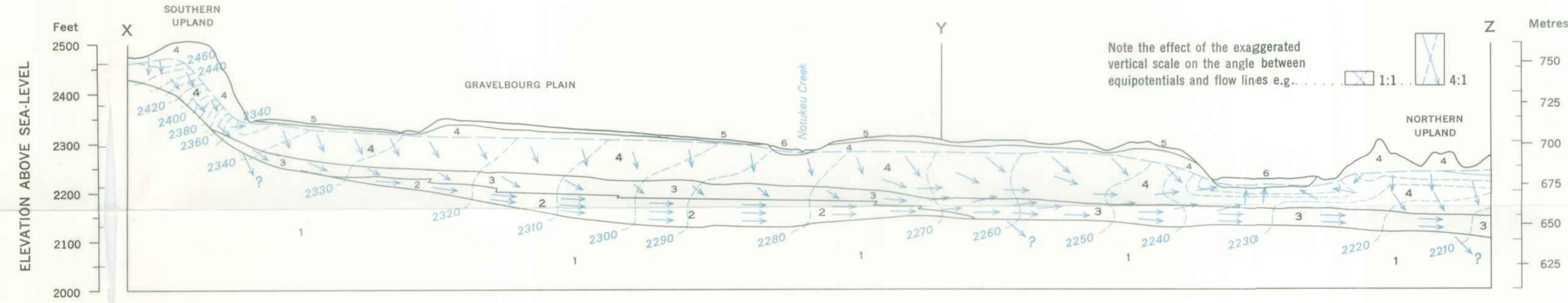


## LEGEND

| 6 | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|
| *Alluvium* | *Glacial lake clay* | *Glacial till* | *Lower stratified drift, silty clay phase* | *Lower stratified drift, sand phase: Gravelbourg aquifer* | *Bedrock surface: Bearpaw shale* |

*Water-table* . . . . . . . . . . *Equipotential line, potential in feet above sea-level* . . . . . . . . . . *Direction of groundwater flow* . . . . . . . . . . →

**Section along line X-Y-Z, showing Gravelbourg area flow pattern**

### LEGEND

*Extent of area underlain by lower stratified drift*
*Extent of area underlain by Gravelbourg aquifer*
*Equipotential lines defining piezometer surface on aquifer; potential in feet above sea-level*
*Drill-holes (A-G, see Figure 7)*
*Piezometer installation (see Figure 7)* . . . . . . P
*Surficial evidence of groundwater discharge*
*Flow net (see section X-Y-Z)* . . . . . . X Z

*Geology by R.A. Freeze, 1963*

*To accompany GSC Bulletin 166, by R.A. Freeze*

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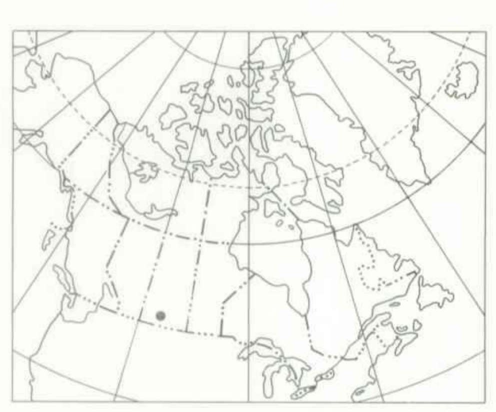
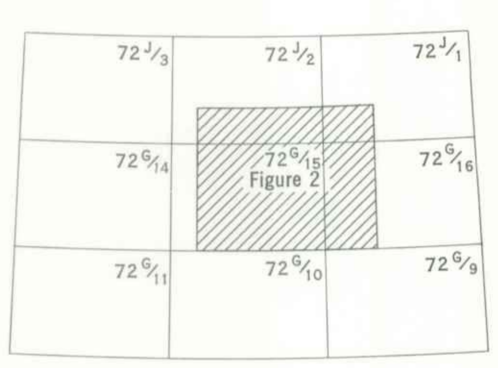
*Road, all weather* . . . . . . Route 43
*Other roads*
*Railway*
*Township boundary*
*Intermittent stream and lake*
*Contours (interval 50 feet)* . . . . . . 2350
*Depression contours*

*Base-map cartography by the Geological Survey of Canada, 1967 from maps published at 1 : 50,000 scale by the Surveys and Mapping Branch in 1960, 1964*

*Approximate magnetic declination 1967, 17° 17′ East, decreasing 2.6′ annually*



INDEX MAP

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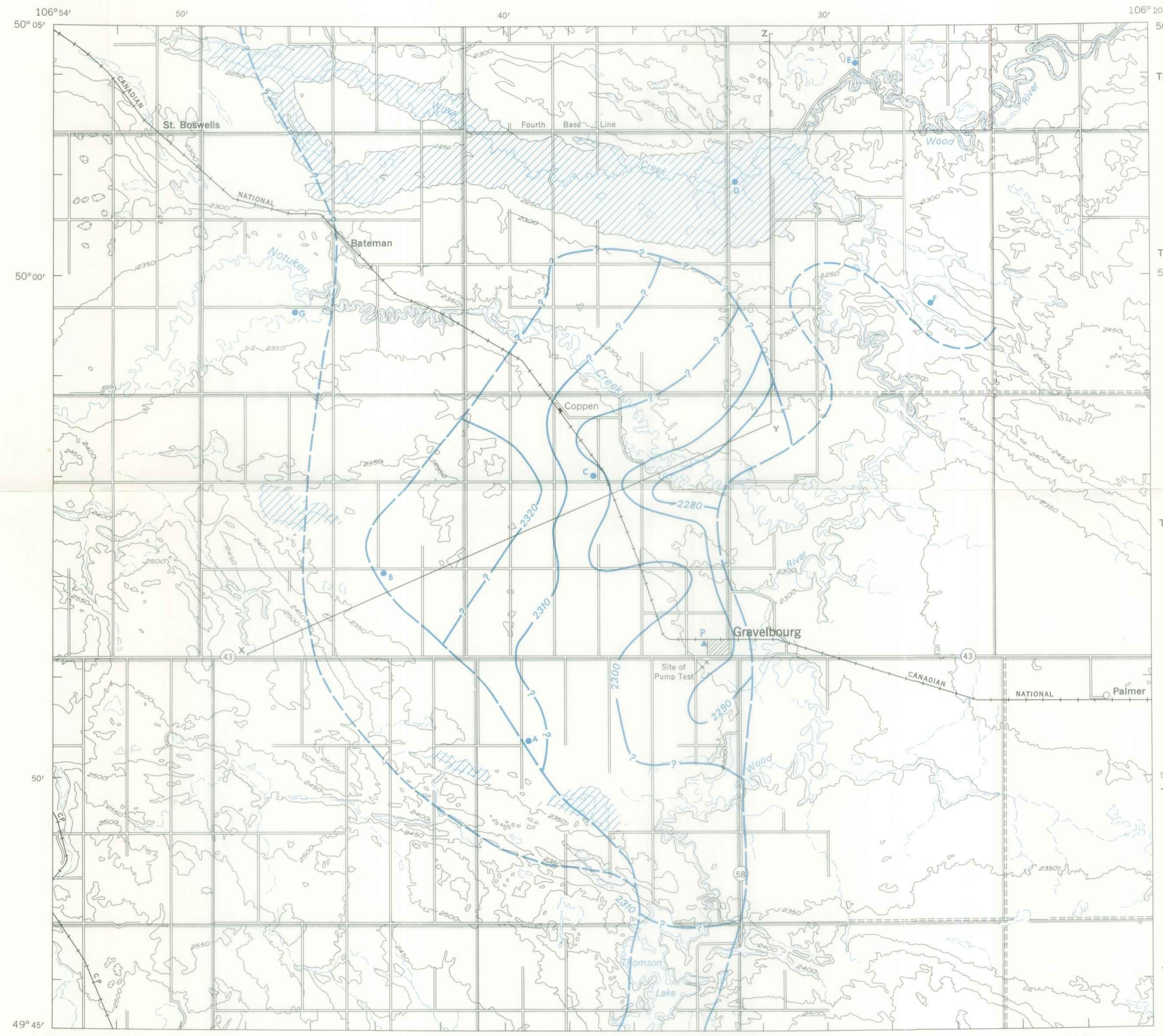


*Published, 1968*

*Printed by the Surveys and Mapping Branch*

**Figure 2. Topography of Gravelbourg area and extent of Gravelbourg aquifer, Saskatchewan.**

Figure 2

**Scale 1:126,720**
**(1 inch to 2 miles)**

Miles 2 0 2 4 6 Miles

Kilometres 3 0 3 6 9 Kilometres